Petrographic Evolution of Lower Gondwana Sediments, Jharia Basin, Bihar.

BY

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I certify that the work presented in this dissertation has been carried out by Mr. Iqbal Ahmed, M.Sc., while he was a Junior Research Fellow of the University Grants Commission. The work is an original contribution to the petrography of Gondwana rocks of the Jharia basin, Bihar, and has not been submitted for any other degree at this or any other University.

I recommend that Mr. Iqbal Ahmed be allowed to submit this work for the award of the Degree of MASTER OF PHILOSOPHY IN GEOLOGY at the Aligarh Muslim University, Aligarh.

S.M. Casshyap

(S.M. CASSHYAP)

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INTRODUCTION

PURPOSE AND SCOPE

The Gondwana rocks commonly occur as outliers in the Precambrian shield in three linear belts, namely: 1) Koel-Damodar valley belt of eastern India; 2) Son-Mahanadi valley belt of east-central India; and 3) Pranhita - Godavari and Satpura valley belts of central India (Fig. 1, inset).

Although a good deal of sedimentological work has been carried out during the past two decades, particularly on rocks of the Damuda Group of eastern India, published accounts of petrography and heavy minerals are yet far too sporadic. The only authentic reference on the heavy mineral study of the Jharia coal measures is a paper by Roy and Sharma published in 1936. Among the petrographic studies, noteworthy are those of Srivastava (1961) and Ghosh and Mitra (1967), both on the Talchir diamictite.

An attempt is made here to undertake a pilot study on the petrography and heavy minerals of dominant rock types, through a stratigraphic column, ranging from Talchir tillite through Barakar and Barren Measures to Raniganj - the four Lower Gondwana formations which underlie the Jharia basin. A comparative petrological study of all these formations is not available for a ready reference.

The Jharia coal field was selected for this study because outcrops of the Gondwana formations are accessible all over the area. Further more, it has been suggested recently on the basis of paleoflow study of this basin (Casshyap, 1977, 1979) that the provenance for these rocks from Talchir to Raniganj time lay to the south of the coalfield.

Field work for this study was undertaken in the winter of 1978, during the course of which rock samples from each formation were collected from lower, middle and upper parts, as far as possible, apart from recording the lithologic features. The results so obtained are used to decipher the composition of the source rocks and the tectonic and climatic factors which may have influenced the composition of these rocks. One of the aims of this study was to estimate the extent to which individual heavy mineral species suffered breaking during the course of manual crushing of rock specimens for sample preparations.

LOCATION AND ACCESS

The Jharia coalfield in the Koel-Damodar valley is the most important coalfield in the country. The eastern edge of the coalfield is 274 km west-northwest of Calcutta. It has well developed communications, both rail and road. The Calcutta - Delhi Grand Trunk Road passes within 13 km to the north of the coalfield and several diversions from it connect the Jharia town, with other important places of the field. Dhanbad, the headquarters of the district is on the Grand Chord line of the Eastern Railway running along the northern boundary of the coalfield. The Gomoh-Barka Kana-Garwa Road Loop of the Eastern Railway passes through the western most part of the coalfield.

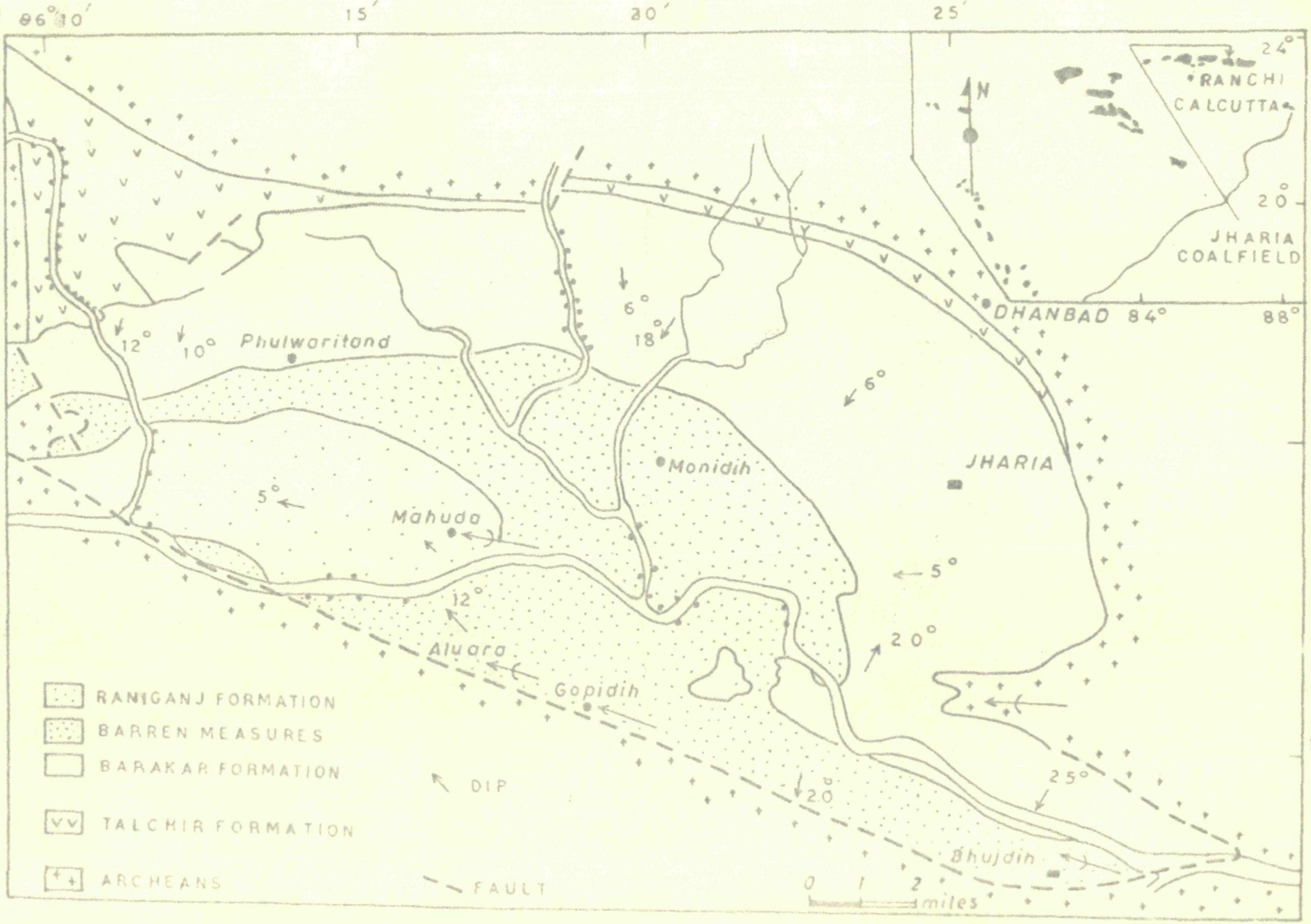

Fig.1: Geological map of Jharia Coalfield (modified after Mehta and Murthy, 1957). Solid dots show lication of the samples used in this study.

The river Damodar traverses the coalfield from west to east and has several tributaries.

ACKNOWLEDGEMENTS

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Chapter - I

STRATIGRAPHIC SETTING

The Jharia coalfield which is roughly sickle shaped lies between latitudes 23° 37' N and 23° 52' N, and longitude 86° 06' E and 86° 30' E in the Dhanbad district of south Bihar. It is a part of Koel-Damodar valley basin of eastern India and contains about 1900 m thick of Gondwana rocks.

The coalfield was geologically mapped first by C.S.Fox (1930) and subsequently by D.R.S. Mehta and B.R.N. Murthy (1957). The basin has since been remapped on a much larger scale by the officers of the Geological Survey of India. A schematic geological map of the Jharia coalfield is illustrated in Fig.1, and a generalised stratigraphic sequence listed in Table 1.

The Lower Gondwana formations of the Jharia coalfield lie unconformably on the Archeans along the northern margin but are faulted against these to the south. Four distinct mappable rock formations recognised in this coalfield are: Talchir (150 m), Barakar (610 m), Barren Measures (634 m) and Raniganj (500m), in ascending order. The structural strike is east-west, swinging sharply towards south and south-southwest in the eastern parts. Regional dips of the strata are largely directed southward, with the result that successively younger rocks from Talchir to Raniganj outcrop towards south (Fig. 1).

TABLE -1 : GEOLOGICAL SUCCESSION AND LITHOLOGIC TYPES IN THE JHARIA COALFIELD

Super Group	Group	Formation	Approximate Thickness (m)	Dominant Lithologies
PERMIAN GONDWANA	DAMUDA	Raniganj	(500)	Fine to medium grained Sandstone, shale and coal seams.
		Barren Measures	634	Predominantly grey and Carbonaceous shale with sandstone and Iron stone bands.
		Barakar	(610)	Arkosic Sandstones, Conglomerates, Shales, Fire clays and thick coal seams.
		Talchir	(150)	Mainly green khaki shales, diamictite and fine to medium grain sandstones.

Permocarboniferous.

Angular Unconformity

ARCHEAN COMPLEX

ARCHEAN BASEMENT

The Archean basement which extends southward upto Chhotanagpur plateau is mainly composed of igneous rocks of acid (granitoid) and basic types, and banded and foliated granitic and hornblende gneisses. Schistose rocks are not so well developed. Broad dykes and masses of epidiorite are abundant in some areas as also quartz reefs and veins of spathic quartz. According to Sadashivaiah (1953), a variety of rock types of both sedimentary and igneous origin occur, which due to regional metamorphism have been converted into impure and crystalline limestones, quartzites, micaceous schists and gneisses, amphibolites, epidiorites and hornblende schists.

GONDWANA SUPERGROUP

Talchir Formation

The lowermost sedimentary formation of the Gondwana supergroup is the Talchir Formation. It derives its name from the erstwhile Talchir State of Orissa where these rocks were first studied and distinguished from the overlying coal-bearing Damuda Group (Blanford et al., 1856, p. 46). In the area under study, the Talchir rocks cropout along the western, northern and eastern margins of the coalfield. (Fig. 1). In addition, these rock are also encountered near the extreme south western margin. Talchir rocks lie directly over Archeans, the Junction between the two being either sharply faulted or distinctly unconformable. The base of this formation in the Jharia coalfield is a diamictite unit, believed to be of glacial origin. The upper part of this formation consist largely of olive green shale and sandstone.

Damuda Group

Barakar Formation

This formation is named after the Barakar river which flows in west Bengal close to the eastern boarder of the state of Bihar, as a tributary to the Damoder river. The Barakar rocks which lie possibly with a slight disconformity over the Talchirs, has the form of a sickle extending from north-west to south-east along the northern margins of the coalfield (Fig. 1). Barakar rocks consist of pebbly sandstone, coarse to fine grained sandstones, siltstone, fire clay, shales, carbonaceous shales and coal seams.

Barren Measures

The term Barren Measures has been applied to the reddish coloured rocks which lie stratigraphically above the Barakar, and are devoid of workable coal, as a rule. This formation has been correlated with the "Ironstone shales" in the Raniganj coalfield and "Motur Formation" in the Pench-Kanhan and Tawa valley coalfields.

Outcrops of Barren Measures occur roughly in the central parts of the Jharia coalfield (Fig. 1). Lithologically these rocks are very similar to those of the Barakar Formation, except for the comparative predominance of shale and the entire absence of coalseams of workable thickness.

Raniganj Formation

The rocks of the Raniganj Formation occupy the oval shaped area in the south-western part of the Jharia coalfield (Fig. 1) which has been designated as Mahuda basin by recent workers. The Raniganj-Barren Measures boundary, like that of Barakar and Barren Measures, is based mainly on the prominance of red colour and absence of workable coal seams in Barren Measures. The contact with the Barren Measures, therefore, is somewhat arbitrary and subjective and has been modified from time to time.

The Raniganj Formation largely consists of micaceous sandstones, which are fine grained than those of Barakars and are sideritic in places. Conglomerates and grits are not common, shale and carbonaceous shale containing coal seams are extensively developed.

Chapter - II

MICROPETROGRAPHY

Among the petrographic studies of Gondwana rocks which have been carried out in recent years, noteworthy are those of Srivastava and Israili (1966) on the heavy mineral studies of Karharbari rocks of Daltonganj, Rizvi (1972) on Daltonganj, Hutar and Auranga, Shukla and Rai (1971) and Qidwai (1972) on the Pench-Kanhan valley coalfields, Ghosh and Mitra (1967) on the Talchir tillites of Damodar valley coalfields, Khan (1978) on Karhabbari and Barakar of East Bokaro coalfield and Tewari (1980) on the Talchir, Karharbari and Barakar formations of Giridih and adjoining coalfields.

This study reports the petrographic characters of some of the dominant rock types of the four Gondawana formations namely, Talchir, Barakar, Barren Measures and Raniganj of the Jharia basin. The study aims at determining the mineralogical and textural characters of the rock types, and variations, if any.

METHODS AND PROCEDURE

The study is based on microscopic examination of 28 thin sections taken from as many specimens of diamictite (3) and sandstone (5) of Talchir and from sandstone of the Barakar (5), Barren Measures (5) and Raniganj (10). Their location is shown in the geological map in Fig.1. Thin section examination was carried out on ortholux II Pol BK microscope. Modal analysis (by volume) was carried out for each thin section using a Leitz six spindle micrometer device. Six to ten traverses were made to cover the entire thin section and modal analysis was computed in terms of major and minor components of the framework.

Two varieties of quartz are recognised as monocrystalline and polycrystalline (Krynine, 1940; Folk, 1961) and their relative abundance estimated,. Feldspars consist of microcline, plagioclase and orthoclase in different proportions. Sand-sized rock fragment components exhibit definite detrital grain boundaries. Matrix is recognised as primary and secondary in origin. In addition, cementing materials are also recognised and their percentage estimated. Other features include estimation of particle size vis-a-vis mineralogy, nature of grain contacts, grain-matrix relationship. Roundness estimation was made for a variety of detrital components here and there.

Sandstone Classification

The scheme of sandstone classification as proposed by Casshyap (1967, 1969) (Fig. 2), is the one used in the present study for reasons spelled out at length elsewhere (Tewari, 1980). In this classification, the same subdivisions as proposed by McBride (1963) have been used for describing "arenite" and "wacke" with appropriate modification in the suffix in the latter. The matrix limit for defining arenite and wacke has been placed

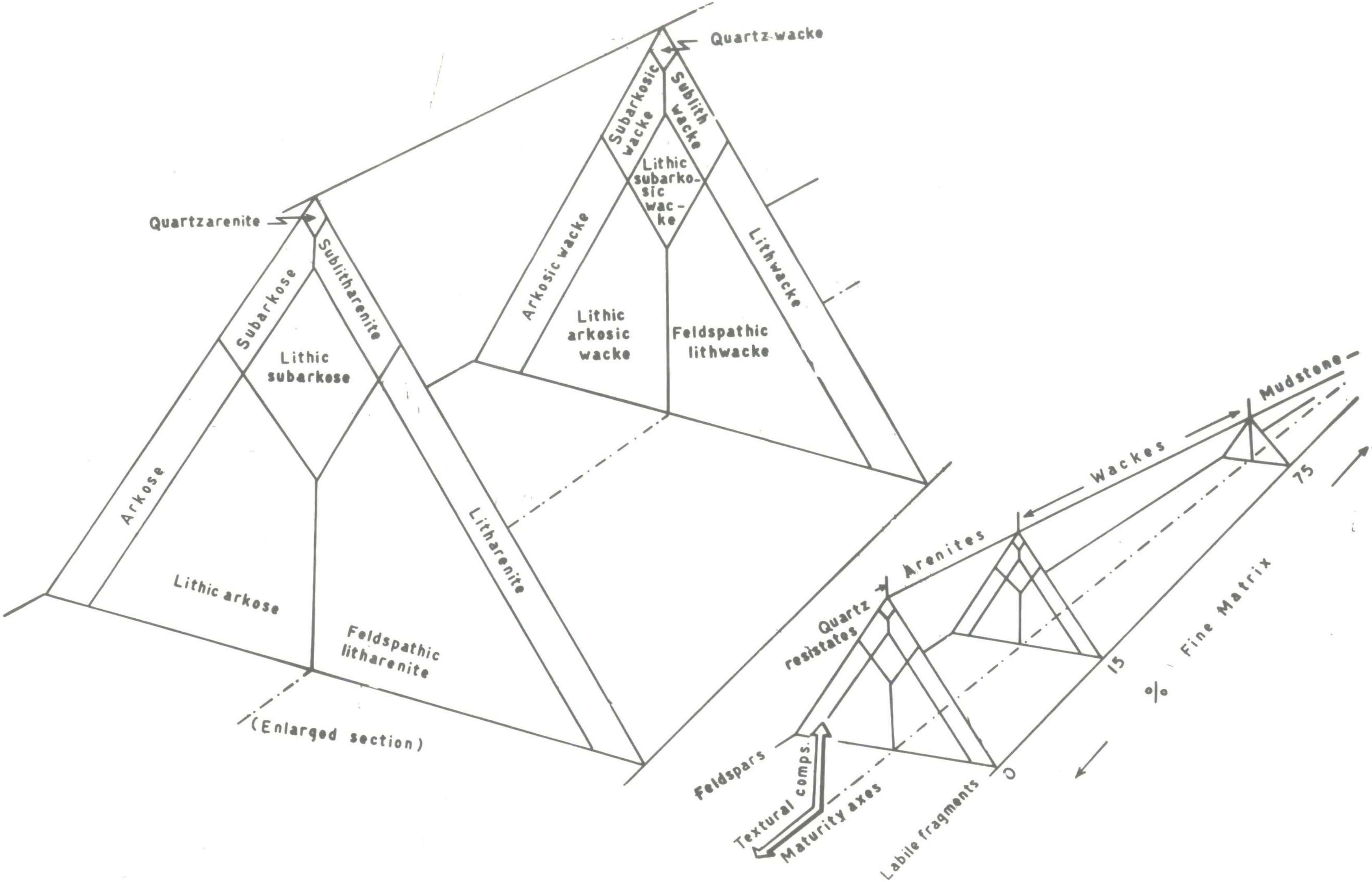


Fig. 2 Sandstone classification as modified by Casshyap (1969) after Gilbert (1954) Dott (1964) and Mc Bridge (1963)

at 15 percent (Casshyap, 1967) instead of 10 percent as recommended by by Gilbert (1954) and followed by Dott (1964).

TALCHIR FORMATION

It is the lowermost Gondwana formation, and comprises of lower diamictite and upper sandstone unit in the given area.

Diamictite (Sandstone Martix)

Greenish coloured sandy matrix of diamictite is compact when fresh but crumbles on weathered surfaces. The framework constituents occurring in diamictite matrix are very poorly sorted, consisting of angular particles of variable sizes and of different composition, scattered in a fine structureless matrix (Plate 1 d). Detrital constituents show practically no point of contact and the intervening space is filled up with matrix, hence resulting in a disrupted framework (Plate 1 d, 2 b). The high degree of angularity of detrital grains is also a noteworthy feature. Quartz grains are invariably angular but rock fragments of schist, slate and phyllite may exhibit better rounding (Plate 1 d).

In general soft fragments show better roundness as compared to the harder ones (e.g. quartzite). Feldspar grains are often subangular to subrounded but angular grains also occur.

Mineral Composition

Modal analysis was carried out for the sandy fraction of diamictite; the results are recorded in Appendix I.

Quartz Resistates

Minerals of the quartz group are by far the most common detritals consisting of mono and polycrystalline quartz, fragments of quartzite and chert.

Monocrystalline quartz (20.1 to 31.4%) shows a size range between 0.05 and 1.35 mm; detrital grains are angular to subangular (Plate 1 d); equidimensional closely followed by elongated grains. Equant grains show a smooth to slightly undulose extinction, while elongated particles commonly show undulose extinction. Boundaries of grains are eaten up by the matrix of groundmass (Plate 1 b, 1 d; 2 a). Mineral inclusions of zircon are not uncommon.

Polycrystalline quartz occurs in small quantity (5.0 to 9.1%) in a size range between 0.20 and 1.42 mm. They show about the same range of roundness and shape as monocrystalline quartz and their grain boundaries are likewise eaten up by matrix (Plate 1 d).

Fragments of quartzite and chert vary from 5.0 to 12.5%, out of which chert is about 2-4%. Some of the quartzite fragments are streched metamorphic type (Hubert, 1960, p. 134, Folk, 1961, p. 69) exhibiting granulated boundaries between each sub-grain (Plate 2 b). They occur in wide range from 2.5 to 0.5 mm in size and are largely subangular to subrounded. Two varieties of chert, recognised on the basis of colour are black and green, having a size range commonly between 2.0 to 0.5 mm but some green chert may be upto 4.0 mm. Fragments of chert are equidimensional, subrounded to rounded.

Feldspars

Feldspars are next to quartz in order of abundance. Three varieties of feldspars recognised on the basis of twinning are microcline showing cross-hatched, plagioclase showing lamellar and orthoclase showing carlsbad twinning.

Microcline constitutes about 5.1 to 10.1% ranging in size from 0.05 to 1.25 mm. They are subangular to angular, even in coarser size (Plate 1 b). There is by and large no relation between grain size and roundness. Equant grains are very common but elongated grains may also be present. Grain boundaries are often corroded. Most of the grains are fresh to slightly altered. Inclusions of zircon, tourmaline and epidote may be present in some grains (Plate 1 b).

Plagioclase content is about one percent, but their roundness values are about the same as those of microcline. Plageoclase is generally albite to oligoclase in composition. Equant grains are common, though elongated grains may also be present (Plate 2 a). Grain boundaries are corroded as in microline. Inclusions of sericite may be present in some altered grains.

PLATE - 1

a - Medium to fine grained lithic arkose, showing angular to subangular quartz with tangential and long contacts. Fresh and subrounded microcline; altered orthoclase in the lower extreme right corner.
Talchir Sandstone (X 30)

b - Coarse to medium grained felspathic lithic wacke, showing subangular to subrounded microcline with inclusions of zircon, tourmaline and epidote.
Talchir diamictite (X 75).

c - Fine to medium grained lithic subarkosic wacke, showing subrounded quartzite fragment with granulated intergrain contacts, detrital grains are angular to subangular.
Talchir sandstone (X 30).

d - Medium grained lithic subarkosic wacke, showing disrupted frame-work. Detrital quartz grains are angular whereas phyllite fragments are subrounded to rounded and tend to merge with the surrounding matrix.
Talchir diamictite (X 30).

PLATE I

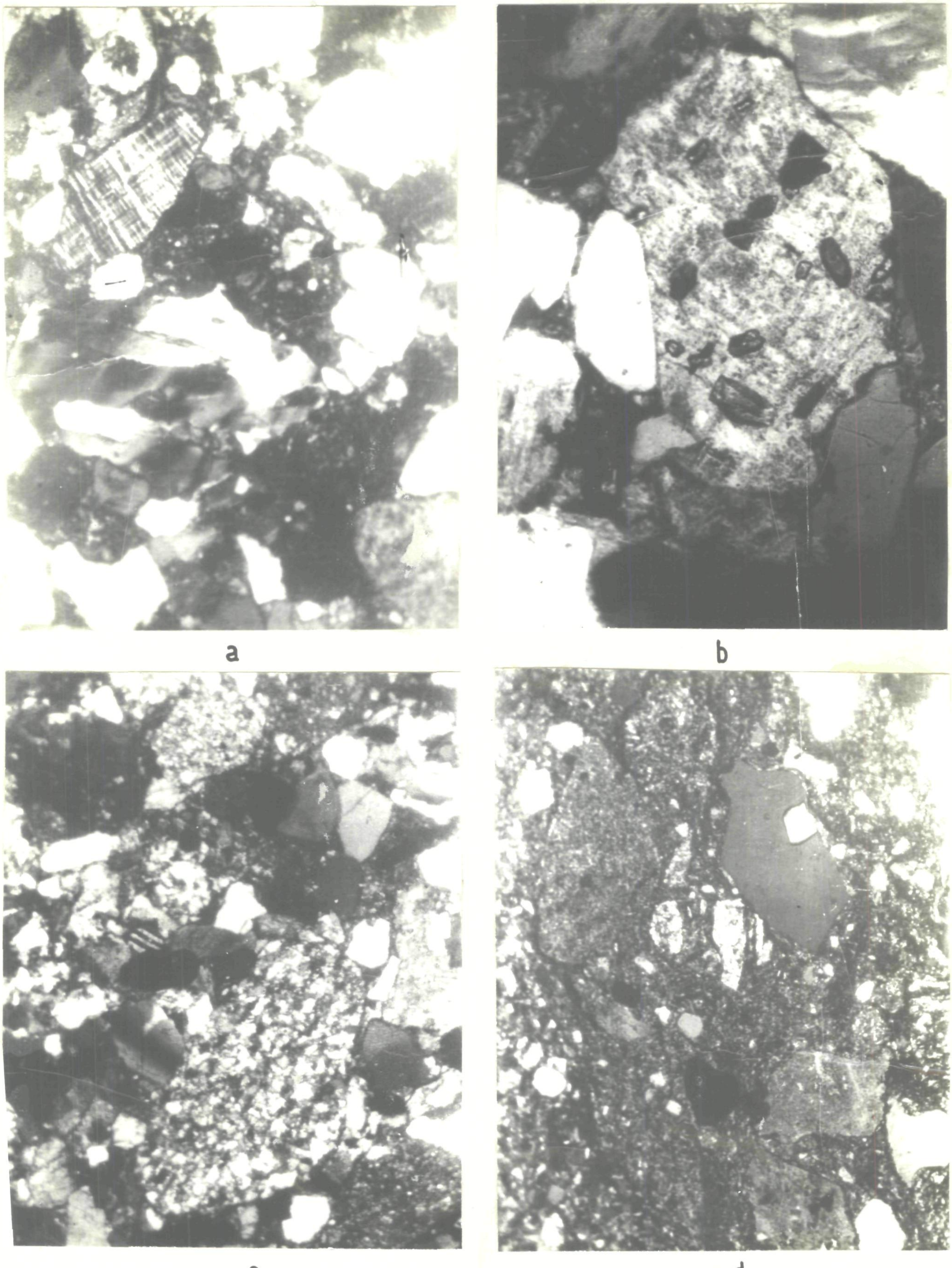


PLATE - 2

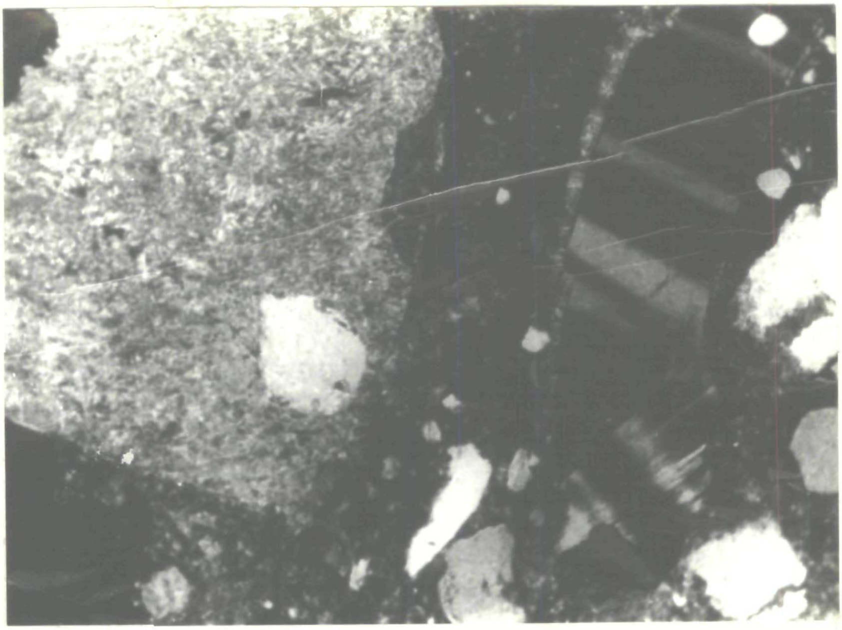
a - Coarse to medium grained felspathic lithic wacke, showing subrounded phyllite fragment, elongated and twisted fresh plagioclase enclosing well rounded quartz as inclusion. Corroded boundaries of detrital quartz in the extreme right side is noteworthy.

Talchir diamictite (X 30)

b - Medium grained lithic subarkosic wacke, showing rounded and stretched metamorphic quartz. Disrupted frame work is due to high matrix and detrital ratio.

Talchir diamictite (X 30).

PLATE 2



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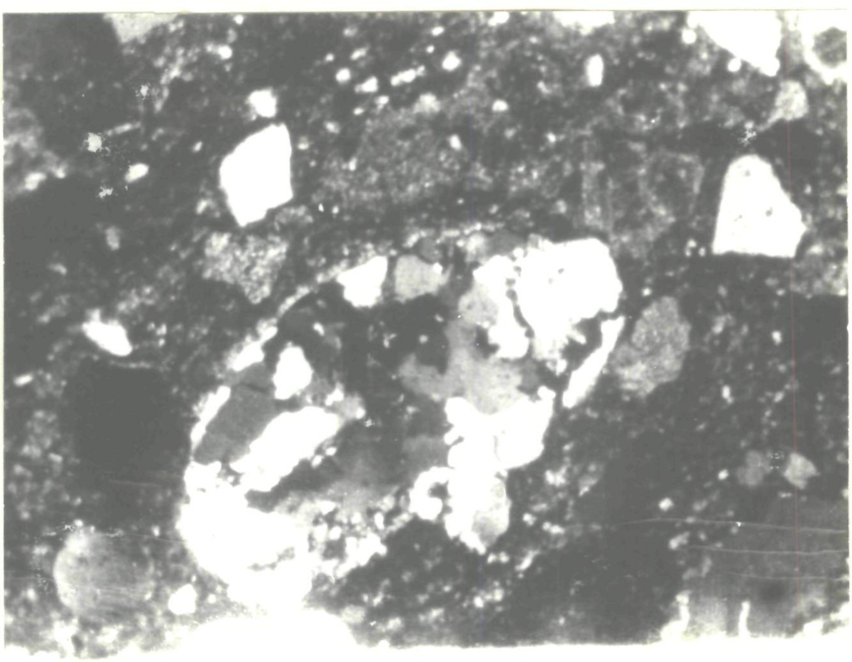


b

The amount of orthoclase is about 3%, ranging in size from 0.05 to 1.2 mm. Grains are commonly subangular. Orthoclase grains show more alteration and often tend to merge into the adjoining matrix (Plate 1 d). Inclusions of sericite are very common. Generally speaking feldspars of finer size are fresh as compared to coarser ones which are altered (Plate 1 b , 2 a).

Mica

Detrital mica (commonly muscovite) is present in small quantity (0-06%) and occurs as conspicuous laths but occassionally a cluster of flakes may be present. The mica flakes are inveriably bent and exhibit frayed ends into which paste like matrix has penetrated along the cleavage planes so much so that often the flakes are physically disrupted and tear apart. The above characteristics show that mica flakes are of detrital origin.

Lithic Fragments

The proportion of lithic fragments varies from 6.2 to 23.8%, depending upon amount of the embeded clast. Rock fragments constitute the coarsest fraction of the framework. Phyllite, schist and slate are among the most commonly occuring types of rock fragments along with basalt and consist of several varieties as follows in order of abundance: calcareous phyllite, sericite-phyllite, magnetite phyllite, micaceous quartzite, felspathic quartzite, altered basalt, altered glassy basalt, mica schist, staurotile schist, slate, granite and siltstone.

Phyllite fragments range in size from 0.65 to 4.2 mm; they are commonly subrounded to rounded (Plate 1 d, 2 a), equant to elongated in shape and often tend to flow between the harder detrital components and finally merge into the surrounding matrix (Plate 1 d). Felspathic and micaceous quartzite fragments are 0.5 to 1.5 mm in size, subrounded to rounded and mostly equant in shape, some may be elongated. Basaltic fragments range from 0.75 to 2.0 mm in size, are subangular to subrounded and equant in shape. Schistose fragments are about 0.5 to 2.3 mm in size. They are mostly subrounded, few grains may be rounded. Slate, siltstone and granite fragments vary in size from 0.4 to 1.0 mm and are likewise subrounded to rounded and equant in shape.

Accessories

Accessory minerals constitute about 2.3 to 3.4% of the rock and consist of garnet, epidote, zircon, rutile, staurolite and opaque minerals.

Matrix

Dark green matrix is the most characteristic feature of the diamictite and occurs abundantly in all samples. Its content varies from 17.4 to 48.7%. Under cross-nicols it consists of clay sized bits of quartz, chlorite and sericite. From its close association with the soft fine grained rock fragments, it is clear that its major part has been derived as a result of crushing of the labile rock fragments. Detrital components of the framework have been marginally replaced by the matrix (Plate 1d).

Therefore, it is clear that part of the matrix is secondary or recrystallised in origin.

Sandstone(Upper Talchir)

The upper sandstone unit in Talchir Formation is mostly grey to dirty white in colour and cross-bedded. This unit shows much variation in texture and composition. Quartz grains comprising of mono and polycrystalline varieties are angular; feldspars are subrounded to rounded, so are rock fragments. Their framework is disrupted to normal. These sandstones can be classified on the basis of amount of matrix and sorting of the framework constituents as 1, poorly sorted sandstone and 2, moderately well sorted sandstone.

Mineral Composition

Quartz Resistates

Monocrystalline quartz varies from 27.2 to 32.0% in sandstones which are poorly sorted to about 42% in those moderately well sorted, and range in size from 0.1 to 1.2 mm. Grains are mostly angular to subangular and show tangential to long contacts (Plate 1a). Other characters are same as described in diamictite. Polycrystalline quartz varying from 7 to 10% ranges in size from 0.5 to 1.4 mm.

Quartzose fragments amounts to 6.5 to 8.8%, out of which chert is about 2%; they vary from 0.3 to 1.0 mm in size and are largely subangular to subrounded (Plate 1 c). Some quartzite fragments exhibit granulated boundaries within the grains, resembling those recorded in diamictite.

Feldspars

Detrital microcline is indeed more common (14 to 18%) in the upper Talchir sandstone than plagioclase (1.2 to 3.0 %) and orthoclase (2 to 3%). Feldspars may range from 1.0 down to 0.13 mm in size. They are subrounded to rounded and are more fresh than altered, although exceptions do occur especially in the case of orthoclase (Plate 1 a, 1 c).

Mica

Muscovite seldom exceeds 2% in poorly sorted sandstone and may be less than 1% in moderately well sorted sandstones.

Lithic Fragments

Sand-sized lithic fragments constitute 11 to 14%, and consist mainly of phyllite, schist and siltstone. Fragments of phyllite, mainly calcareous, are rounded to subrounded and may range in size from 0.3 to 0.9 mm. Coarser fragments are more common in poorly sorted sandstone than in those moderately well sorted (Plate 1a, 1 c). Schist and siltstone fragments are subrounded to rounded showing the same size range as that of phyllite.

Accessories

Among the accessory minerals are garnet, actinolite-tremolite, zircon, epidote, tourmaline and opaques. Their percentage vary from 1.0 to 3.5 in poorly sorted sandstohe and goes up to 4.3 in moderately well sorted sandstones.

Matrix

Matrix occurs in variable quantity, ranging from 28% down to 5%. The resultant sandstone types are poorly sorted to moderately well sorted respectively.

BARAKAR AND BARREN MEASURES

Rocks of the Barakar and Barren Measures are well exposed along the northern margins, and central part of the Jharia coalfield, respectively (Fig. 1). These formations consist mainly of sandstone, shale, siltstone and carbonaceous shale (Table 1). Coal seams are restricted only to the Barakar Formation. Petrographic study is undertaken for coarse, medium and fine grained sandstone types. In handspecimens sandstone is buff-brown to earthy coloured in the case of Barakar and brown to reddish in Barren Measures. The sandstone bodies in either case are laterally continuous to channel shaped, profusely cross-bedded to horizontally bedded. Five samples of Barakar sandstone and 5 of the Barren Measures taken from different localities (Fig. 1), were subjected to thin section examination with a view to analyse their texture and mineralogy and compare these characters with those of the underlying Talchir sandstone described earlier.

Petrographically, the bulk of the sandstones in either formation are moderately to poorly sorted, submature to slightly immature. Compositionally they are commonly subarkoric wacke in Barakar and subarkose, containing mineral cement in excess of matrix in the case of Barren Measures. The framework is normal to slightly disrupted; the latter more so in the sandstones of Barakar Formation. Comparative results of the modal analysis of Barakar and Barren Measures along with Talchir and Raniganj are listed in Table 2; and their complete modal analysis is recorded in Appendix 2 and 3.

Mineral Composition

Quartz Resistates

Detrital quartz forms the bulk of the rock. However, unlike Talchir sandstone, monocrystalline quartz increases to about 40.8 to 50.5% in the case of Barakar and 38.1 to 55.2% in Barren Measures. Polycrystalline quartz remains about the same (5.2 to 12.8%) as in the case of Talchir (5.1 to 10.1). Quartzite and chert fragments decrease from 4.5 to 8.9% in Barakar to 2.1 to 3.7% in the case of Barren Measures. The different species of quartz resistates as referred to above, occur in very coarse grained sandstone down to medium and fine sandstone.

Monocrystalline grains are subrounded to subangular, equidimensional and may show smooth to slightly undulose extinction (Plate 3a, b,c,d). However, it is not uncommon to find rounded monocrystalline quartz with abraided overgrowths (Plate 4b),

PLATE - 3

a - Fine to medium grained subarkosic sandstone, showing subrounded to subangular quartz. Fresh plagioclase and microcline occur subordinately.

Barakar sandstone (X 30).

b - Medium to coarse grained subarkosic wacke.

Barakar sandstone (X 30).

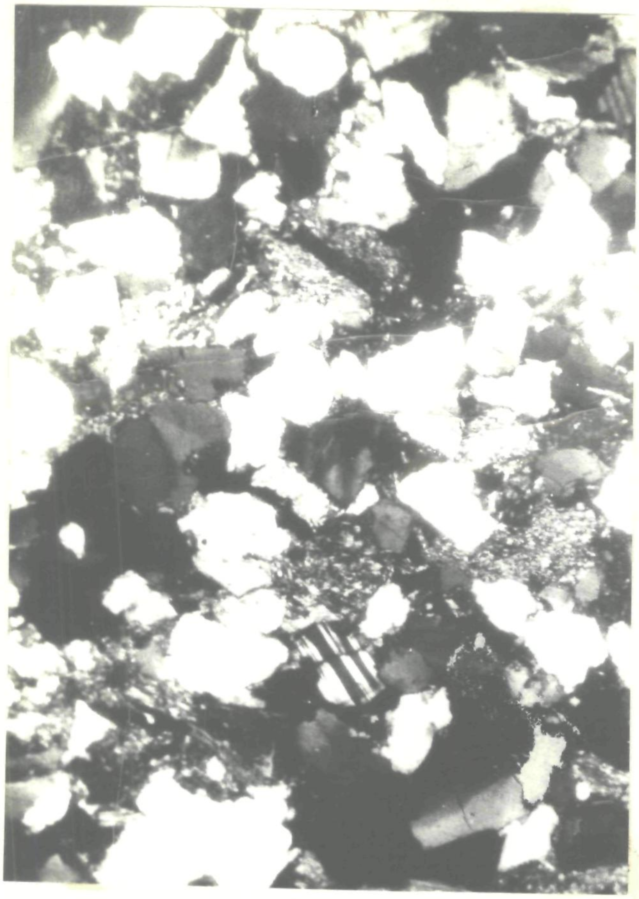
c - Medium to coarse grained subarkosic wacke, showing angular to subangular detrital quartz. Elongated and rounded shale fragment in the centre is conspicuous.

Barakar sandstone (X 30).

d - Medium to fine grained lithic subarkosic wacke, showing disrupted framework. Detrital quartz exeute corroded outline. Fragment of phyllite in the centre.

Barakar sandstone (X 30).

PLATE 3



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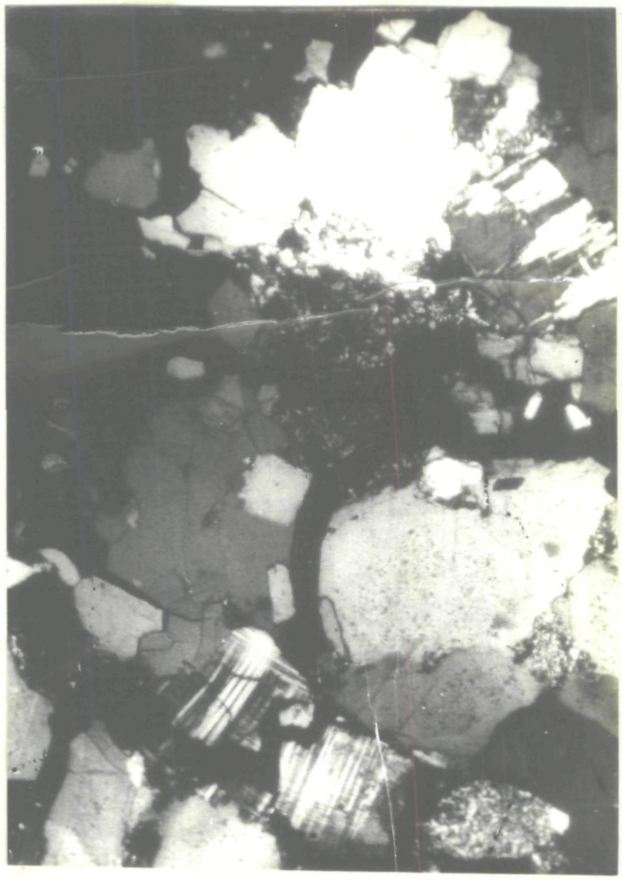

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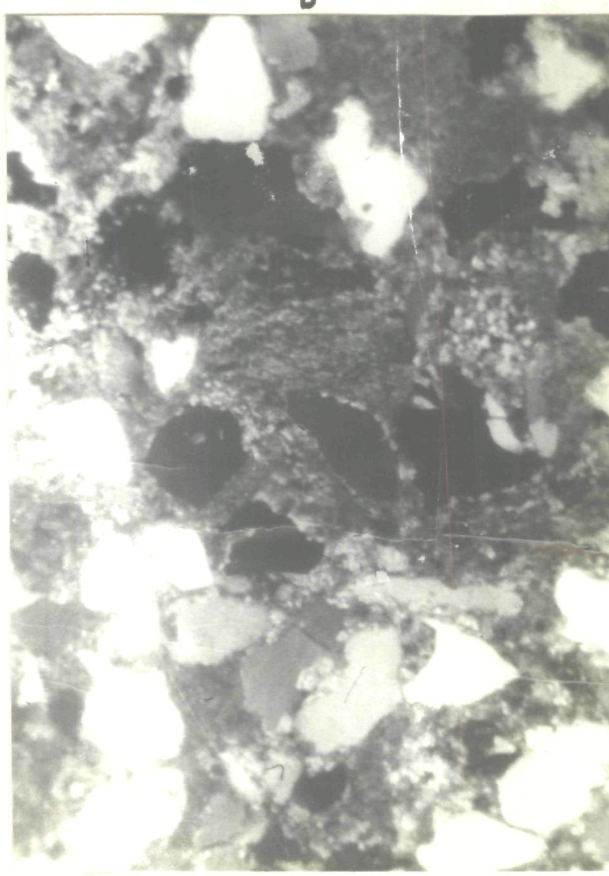


d

particularly in Barren Measure sandstones. Indeed, in this formation finer detrital quartz grains are better rounded than coarser ones, an intresting feature suggestive of textural inversion (Folk, 1963). Such textural inversion in quartz grains is seldom observed either in the Barakar or Talchir. In coarse sandstone of the Barakar as in the Raniganj are some of the quartz grains found to be fractured (Plate 3b). These grains show irregular to sutured contacts, though tangential and long contacts are not uncommon. Quartz grains may contain well developed inclusions of zircon, tourmaline and moscovite in the case of Barakar and tourmaline (euhedral to rounded), epidote, muscovite biotite and gas in Barren Measures (Plate 4d). Gaseous inclusions may be arranged in a row.

Polycrystalline quartz are mostly subrounded, though some rounded grains are also present. They are equidimensional to elongated and show highly undulose extinction (Plate 4a). Some of the quartz grains show corroded boundaries (Plate 4b, 3d). Inclusions are not so common in polycrysalline quartz as in monocrystalline quartz.

Among the Fragments of quartzite and chert, the latter is always less than 2%. These fragments commonly show the same roundness and shape as those of monocrystalline quartz. Elongated grains of quartzite resemble streched metamorphic type (Folk, 1961) showing slightly sutured internal grain boundaries. Grains of chert are better rounded than other grains (Plate 3a).

PLATE - 4

a - Coarse grained subarkosic sandstone, showing polycrystalline quartz. Undulatory extinction in quartz is noteworthy.

Barren Measures sandstone (X 30).

b - Medium grained subarkosic sandstone, showing angular to subangular and well rounded quartz, the former exhibit corroded outline.

Barren Measure sandstone (X 30).

c - Medium grained subarkosic sandstone, showing angular to subangular quartz and fresh microcline. Mica flakes occur in small amount.

Barren Measure sandstone (X 30).

d - Medium grained subarkosic sandstone, showing inclusions of tourmaline and epidote in angular to subangular quartz. Gaseous inclusions in quartz are arranged in preffered manner.

Barren Measure sandstone (X 30).

PLATE 4

a

b

c

d

Feldspars

Detrital feldspar which is next to quartz in abundance comprises of the same species as in Talchir. The content of microcline is around 4.6 to 12.5% in the case of Barakar and 8.2 to 12.1 in Barren Measures. Content of microcline is more in medium to coarse grained varieties than fine grained ones. Grains are commonly angular to subangular (Plate 4c), though subrounded to rounded grains may also be present especially in medium to fine grained sandstones. Although size and roundness relationship was not rigrously investigated, there is evidence to suggest that finer grains of microcline are by and large better rounded (subrounded to rounded) than coarser grains. This is particularly so in the case of Barren Measures. Equant grains of microcline are more common than elongated ones, their boundaries are often corroded by the surrounding matrix or mineral cement.

Plagioclase is scarcely developed in Barakar (0 - 1.5%), though is a bit more in the Barren Measures (3.1 - 4.4%). It occurs in about the same size range as does microcline. Compositionally, plagioclase range from oligoclase to andesine. Orthoclase feldspar varies from 2.1 to 3.1% in Barakar and 1.2 to 4.4 in Barren Measures, and is more common in fine to medium grained sandstone, though grains up to 0.5 mm size may be present in medium to coarse varieties.

By and large, feldspars of finer size are less altered than those of the coarser size. Among the diffrent species orthoclase is relatively more altered than plagioclase and microcline. Among the two sandstones, there are more highly altered grains of feldspar including those of microcline in Barren Measures than in the Barakar. Inclusions of sericite, muscovite and gas and other unidentified minerals may be present in some grains, especially orthoclase and plagioclase, along the cleavage planes.

Mica

Detrital mica is always less than 1% in the case of Barakar and upto 3.1% in Barren Measures. It is mostly muscovite but grains of biotite (both detrital and secondary) may also occur. Moscovite exhibits the same general characters as in Talchir sandstones.

Lithic Fragments

Lithic fragments, indeed, show a rapid decline from lower diamictite (6.2 to 23.8%) and upper Talchir sandstone (11.3 - 16.7%) to Barakar (3.1 - 8.5%) and Barren Measures (2.1 - 5.8%) (Table 2). This decrease in lithic fragments may be related to corresponding increase in the content of monocrystalline quartz as described above. Four types of labile rock fragments are more common in Barakar sandstone including siltstone, phyllite, schist and shale. By contract, sandstones of Barren Measures include as many as eight types of rock fragments namely, calcareous phyllite, phyllite, TABLE - 2: Comparative results of modal analysis of various formations of Jharia Coalfield.

FORMATION	TALCHIR		BARAKAR	BARREN MEASURES	RANIGANJ
MINERAL COMPOSITION	DIAMICTITE	SANDSTONE			
Monocrystalline Quartz	20.1 -30.4%	27.2 -42.4%	40.8 - 50-5%	38.1 - 55.2%	33.0 - 56.0%
Polycrystalline Quartz	5.0 - 9.1%	7.0 -10.0%	5.2 - 10.5%	6.4 - 12.8%	4.8 - 10.8%
Quartzite Fragments & Chert	5.0 -12.5%	6.5 - 8.8%	4.5 - 8.9%	2.1 - 3.7%	1.02- 7.1%
Microline	5.1 -10.1%	14.0 -18.0%	4.6 - 12.5%	8.2 - 12.1%	3.6 - 20.2%
Orthoclase	2%	2 - 3%	2.1 - 3.1%	1.2 - 4.4%	2.5 - 8.0%
Plagioclase	1%	1.2 - 3.0%	0.0 - 1.5%	3.1 - 4.4%	2.1 - 6.1%
Lithic Rock-Fragments Fragments	6.2 -23.8%	11.0 - 17.0%	3.1 - 8.5%	2.4 - 5.8%	2.8 - 10.8%
Mica	0.0 - 0.6%	2%	1%	0.2 - 3.1%	0.2 - 3.7%
Cement	-	-	0.7 - 4.2%	1.8 - 5.8%	2.9 - 33.6%
Matrix	17.4 -48.7%	5.0 - 28.0%	11.1 -23.6	5.7 - 12.5%	1.3 - 9.7%

magnetite phyllite, phyllitic quartzite, siltstone, quartzite schist, shale and schist. It may be noted that there is far greater heterogeneity of rock fragments in the sandstone matrix of Talchir diamictite as reported earlier.

Bulk of the sand-sized rock fragments appear in coarse to medium sand size; their identification in fine grained size is not definitive. The rock fragments exhibit lack of roundness and are commonly subangular though there are exceptions in that phyllite and shale fragments are not uncommonly subrounded to rounded (Plate 3c, 3d). Softer rock fragments occasionally exhibit evidence of crushing between the harder detrital grains like quartz (P (Plate 3d,4d).

Accessories

Minor accessories constitute 0-1.2% of the rock and commonly consist of epidote, zircon, tourmaline, garnet and opaques.

Matrix

The interstitial matrix is greyish to brownish in colour in the case of Barakar and reddish to greyish brown in Barren Measures. The matrix content varies from 11.0 - 23.6% to 5.7 - 12.5%, respectively. Compositionally, it is fine silty clay, recrystallised to chlorite, sericite paste in the case of Barakar and silty quartzite, sericitic, clacareous clay in Barren Measures. In either case matrix is mostly secondary.

Cement

The amount of cement varies from 0.7 - 4.2% in the case of Barakar and 1.8 - 5.8% to locally as high as 21.5% (sample No. 7/12) in Barren Measures. Silica is a common cementing meterial followed by sideritic carbonate, and limonite.

RANIGANJ FORMATION

Rocks of this formation occur in the oval shaped area in the south western part of the Jharia basin, which is designated as Mahuda basin (Fig. 1) by recent workers. Among the prominent lithofacies are coarse to medium grained sandstone, fine grained silty sandstone, inter-bedded shale and siltstone and coal. Sandstone is pale-brown to earthy in colour, sandstone bodies occur commonly as discontinuous lenses which tend to coalese laterally. Cross-bedding, mostly trough shaped, is widely developed. Other sedimentary structures are syndepositional scour and fill and small and large erosional channels. Horizontal to wavy laminations, cross-laminations, rib and furrow structures and ripple marks are also present especially in fine grained sandstone.

Petrographically bulk of those sandstones are moderately sorted and submature. Compositionally they are mostly subarkose, lithic subarkose, lithic arkose and arkose. The framework is always normal. Complete results of modal analysis are recorded in Appendix 4.

Mineral Composition

Quartz Resistates

As in the underlying formations, detrital quartz forms the bulk of the rock. Amount of monocrystalline quartz (33 -56%) and polycrystalline quartz (4.8 - 10.8%) is about the same as in the underlying Barren Measures (Table 2). Quartzite and chert fragments are relatively more (1-7.1%) in this formation (Table 2). The different species of quartz resistates as referred to above occur in very coarse grained sandstone down the medium and fine sandstone.

Monocrystalline grains are commonly subrounded to subangular (Plate 5, a,b,c) as in the case of Barakar and Barren Measures. However, it is not uncommon to find rounded monocrystalline quartz with abraided overgrowths (Plate 5a). Finer detrital quartz grains are less rounded (subangular to subrounded) (Plate 5c, 6b) than coarser ones. Some of the coarser quartz grains are fractured (Plate 5b) as in the case of Barakar Formation. Grains are mostly equant showing smooth to slightly undulose extinction and sutured to embayed contacts; some grains show tangential contacts. In some thin sections (JR 10 & JR 28) grains are not in contact because of high amount of carbonate cement (30%) resulting in a disrupted framework (Plate 5b). Inclusions of well rounded

PLATE - 5

a - Coarse to medium grained arkosic sandstone, showing abraided overgrowth on rounded detrital quartz, inclusions of well rounded zircon, muscovite and tourmaline are common.

Raniganj sandstone (X 30).

3 - Coarse grained subarkosic sandstone, showing subrounded to subangular fractured quartz. Matrix is dominantly made up of carbonate resulting in (pseudo) disrupted framework.

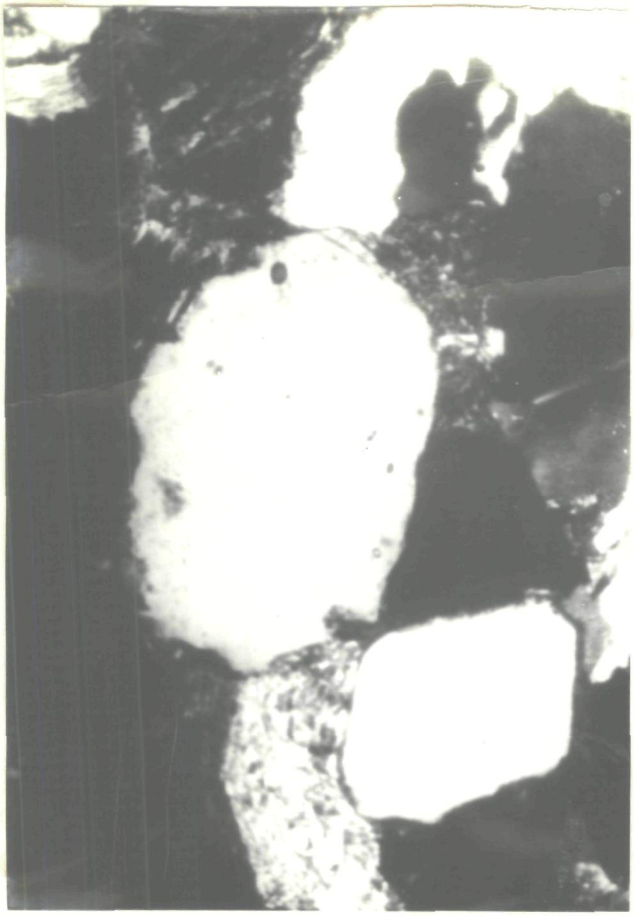
Raniganj sandstone (X 30).

c - Medium grained subakkosic sandstone, showing angular to subangular quartz; rounded and fresh microcline. Cryptocrystalline silica in centre is conspiquous. Raniganj sandstone (X 30).

d - Medium grained lithic arkosic sandstone, showing fragments of quartzite, chert (rounded) and cryptocrystalline silica as cement.

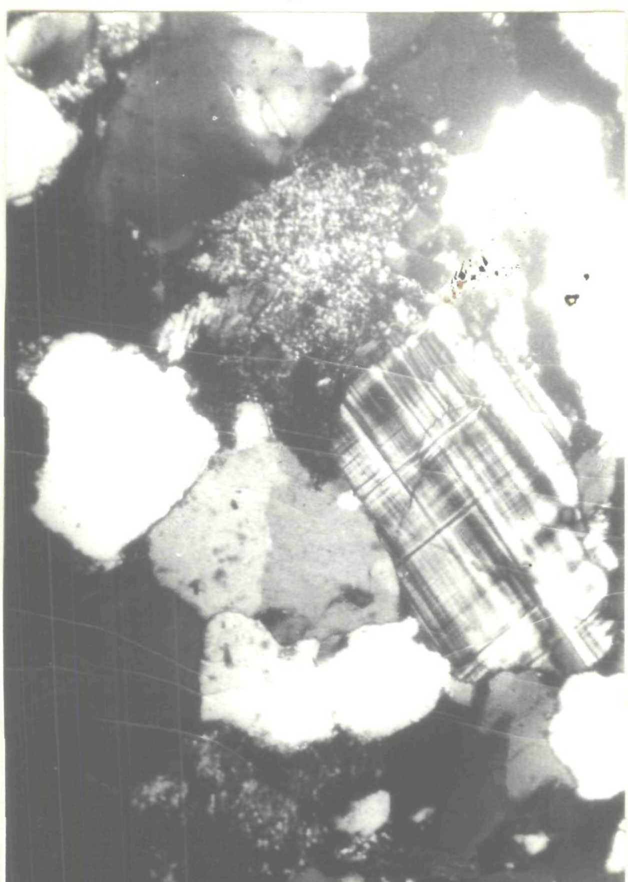
Raniganj sandstone (X 30).

PLATE 5



a

b



c

d

zircon, muscovite, tourmaline and gas may be present in some grains (Plate 5 a,b).

Polycrystalline grains show the same range of roundness as do monocrystalline grains. Individual grains are commonly equant to elongated showing slightly to highly undulose extinction. Some of the elongated grains resemble stretched metamorphic quartz (Plate 6a). Grain boundaries may be corroded in both mono-and polycrystalline quartz (Plate 5b, 6a,6b). The amount of quartzite and chert is about 1 - 7.1%, the latter being 2 - 3%. They are commonly subrounded (quartzite) to rounded (chert) (Plate 5d).

Feldspars

Unlike the underlying formations, microcline increases to about 3.6 - 20.2% (Table 2), particularly in very coarse to coarse sandstone and is less in fine grained sandstones. Grains are subrounded, occassionally rounded or subangular (Plate 5c). Some coarser grains of microcline are characterstically cracked. Grain boundaries are often corroded. Tangential to long contacts are common, though embayed to slightly sutured contacts may also be present. Grains are fresh to moderately altered.

sp The amount of plagioclase increases further (2.0-6.1%) in this formation as compared to the underlying Barren Measures (Table 2). Size androundness of these grains is same as those of microcline, though the grains are slightly to heavily

altered. Cha

altered. Orthoclase varies from 2.5 - 8.0% in the same size range as those of microcline and plagioclase; it is subrounded to rounded and exhibits a high degree of alteration. At places it tends to merge into the matrix (Plate 6a). Inclusions of sericite and gas are common.

Mica

The amount of micaceous minerals further increases from 0.2 - 3.7 (Table 2). Generally speaking, micaceous minerals are more in fine to medium grained sandstones than in coarse to very coarse sandstones. Among these, detrital muscovite is more common than biotite (both detrital and secondary). Flakes of muscovite are torn apart along their cleavage planes and bent round harder detrital grains. At places they show the tendency to merge with surrounding matrix.

Lithic fragments

Sandesized fragments of phyllite, schist and granitoid rock occur in order of abundance. Phyllite is by far the most common of all, ranging from 1.8 - 8.0% and occurs in coarse to medium grained sandstone. Fragments of phyllite are mostly tabular, subrounded to rounded, and at places tend to flow between the harder detrital grains (Plate 6a). Schistose fragments vary from 1 -4.8% and contain foliated grains of quartz, sericite, chlorite and mica etc. They show about the same size range as those of phyllite and are commonly subrounded. Granitoid

PLATE - 6

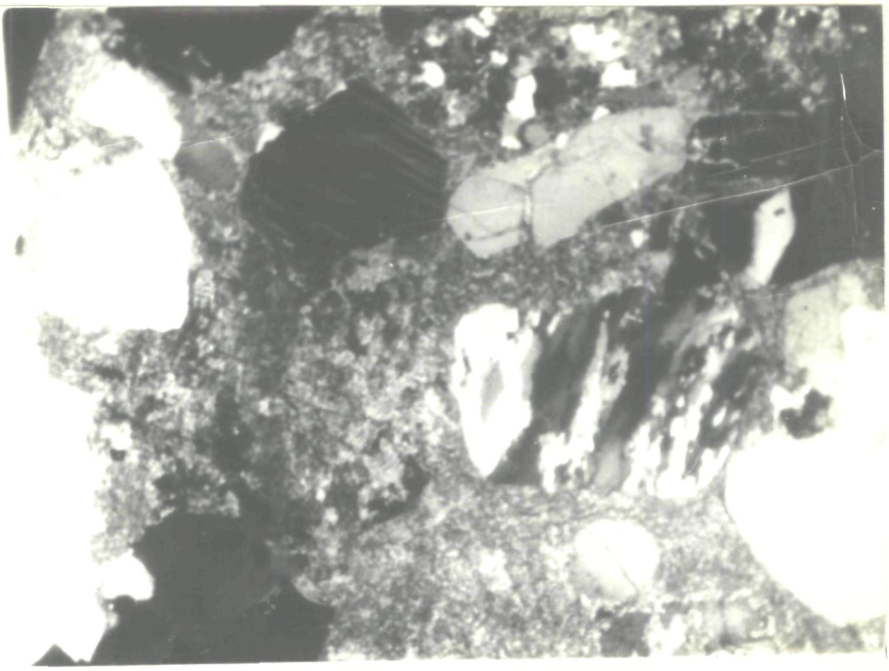
a - Medium to fine grained lithic subarkose, showing subrounded to rounded stretched quartz, altered orthoclase. Boundaries of detrital quartz are coroded by surrounding matrix.

Raniganj sandstone (X 30).

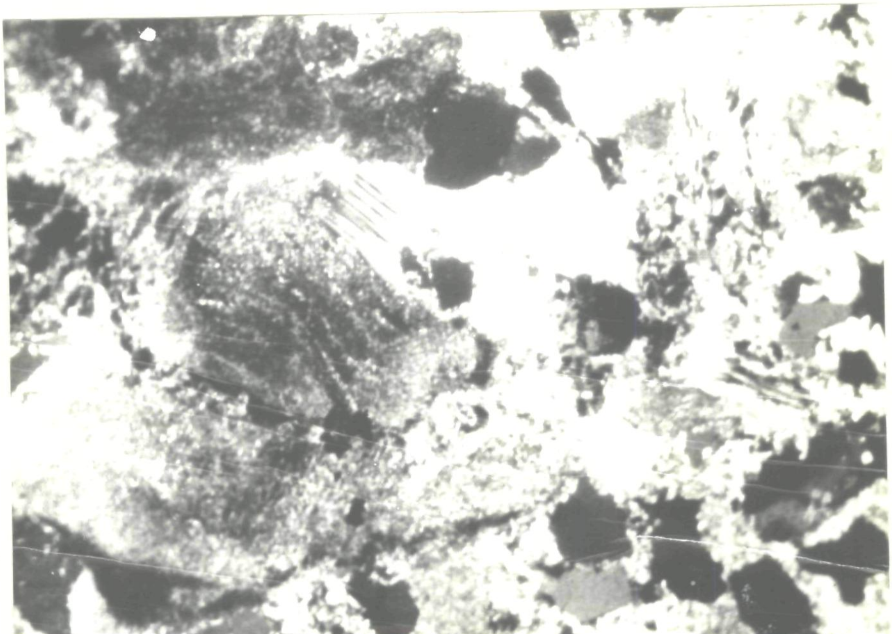
b - Medium to fine grained lithic subarkose, showing fragments of petrified plants.

Raniganj sandstone (X 30).

PLATE 6



a



b

fragments consisting of compound grains of quartz and feldspar occur sporadically in about the same size as other fragments. They are subrounded to subangular.

Petrified Plant Fragments

Sandstones may contain a variety of petrified plant fragments some of which show well preserved internal tracheids and cellular structure, indicative of perfect petrification (Plate 6b). The replacing agent is limonitic cement in most cases.

Accessories

Minor accessories (1%) consist of garnet, epidote, tourmaline, zircon and opaques.

Matrix

The interstitial matrix varies in amount from 1.3 - 9.7%. Compositionally it is fine silty, sericitic and calcareous clay. Most part of matrix is secondary derived as a result of deformation and squashing of pelitic rock fragments.

Cement

Cryptocrystalline silica (Plate 5c,d) is the most common cementing material (1-10.8%) followed by limonitic cement (0-4.0%). Carbonate cement is local; but in some thin sections (JR 10 & JR 28), it is as high as 30% (Plate 5b), resulting in a disrupted framework.

Classification

For each Formation the amount of quartz resistates, feldspars and lithic rock fragments was recalculated to 100% (Appendix 5,6,7, & 8) and plotted on equilateral triangles (Fig. 3a,b,c, & d). The petrographic types so recognised in different formations are as follows:

Formation		Rock Types	No. of samples
Raniganj		Subarkose	4
		Lithic subarkose	3
		Lithic arkose	2
		Arkose	1
Barren Measures		Subarkose	5
Barakar		Subarkosic wacke	3
		Subarkose	1
		Lithic subarkosic wacke	1
Talchir	Sandstone	Lithic subarkosic wacke	3
		Lithic subarkose	1
		Lithic arkose	1
	Diamictite	Lithic subarkosic wacke	2
		Felspathic lith-wacke	1

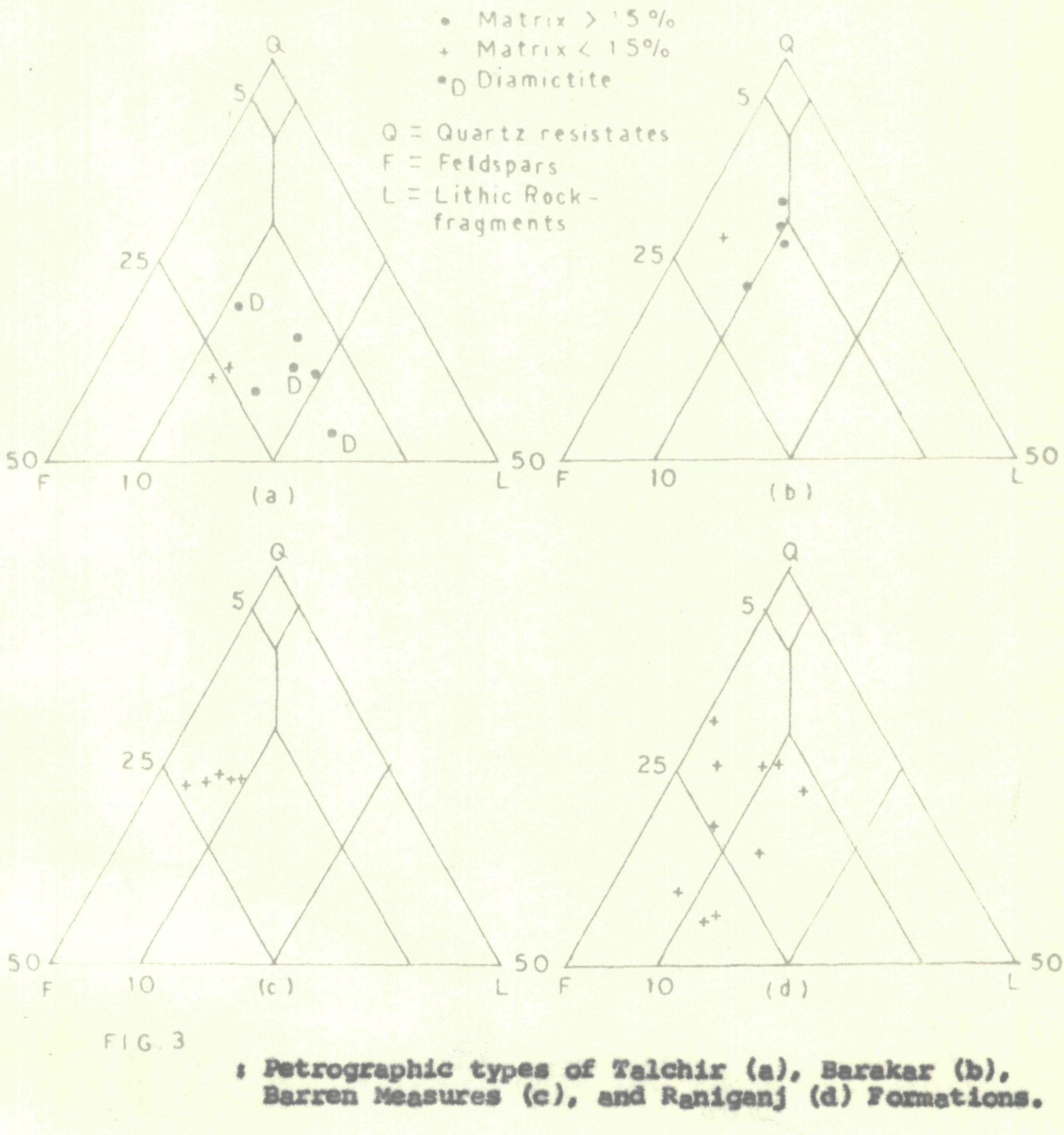


FIG. 3 : **Petrographic types of Talchir (a), Barakar (b), Barren Measures (c), and Raniganj (d) Formations.**

Chapter -III

HEAVY MINERAL ANALYSIS

The study of heavy mineral assemblage has been made to suppliment the results of petrography. Further, the study was undertaken for the following purpose:

1. to investigate texture and composition of different heavy species in different formations, and differences, if any; and

2. to infer abrasion history of transport and evaluate the possible composition of provenance.

METHODS AND PROCEDURE

Five samples from each formation were selected for the study of heavy minerals. Most of the rock types being hard and compact, and not amenable to dissaggregation, were crushed gently in an iron mortar. A preliminary examination of crushed material showed variable breaking effect on mineral grains, yet some stable minerals (e.g. zircon, tourmaline, rutile and garnet) have either completely escaped or show more or less effect of breaking.

Each crushed sample was sieved into four different size fractions (0.25, 0.149, 0.074 and 0.062 mm) to analyse the variation in the heavy species with respect to grain size, wherever possible. The sieved fraction was treated with 15% HCl and gently heated for about 15-20 minutes to remove the iron oxide coating around the heavy grains. Although, some of the heavy minerals, such as apatite, if present, may have been leached out partially or completely (Krumblin and Pettijohn, 1938; Hubert, 1960; Stanley, 1965 p. 25), this treatment was unavoidabl in view of the opacity caused by the iron oxide coating. The fraction was then washed, dried and weighed.

About 4-5 grams of cleaned fraction was taken for heavy mineral separation. The heavies were separated by centrifuse method described by Griffiths (1967, p. 208) using bromoform (sp. gr. 2.86) as the separating liquid. The heavy mineral crop so obtained after running the centrifuse for about 15 minutes or so was washed in alcohol, dried and weighed to compute the amount (by weight and percentage) of the bulk heavy mineral crop in each fraction. A small fraction of the heavy minerals so obtained was mounted on a glass slide using canada balsom for examination under petrological microscope. Some 250 - 300 grains, including opaques, were counted in each slide.

Heavy mineral species were identified on the basis of their optical characters and overall appearance. Verieties of individual species were also distinguished, wherever possible. Number percentage of each species in different size fractions was calculated as showin in Appendix 9, 10, 11, & 12. In addition, percentage of broken and unbroken heavy mineral grains was calculated separately, wherever possible (Appendix, 13, 14, 15 & 16). Roundness was estimated visually (Krumbein, 1941) for those grains only, which escaped crushing effect during sample preparation.

Interestingly, the average amount of heavy minerals (by weight) shows a systematic decrease from Talchir (1.3%) through Barakar (0.46%) and Barren Measures (0.39%) to Raniganj sandstones (0.24%) as recorded in Appendix, 17. The systematic decrease in the amount of heavies is recorded also from lower to upper parts in each formation. This progressive decrease in the amount of heavy minerals, is accompanied by a systematic variation in the composition and roundness of certain heavy mineral species as discussed later.

Talchir Formation

Mineralogy

The heavy mineral crop in Talchir Formation consists of the following species in order of abundance;

Garnet

On an average garnet ranges between 62.8 and 47.9% in the samples of lower Talchir but in those of upper Talchir, it goes down abruptly to 12.3% (Table 3; Fig. 4a). The garnet content decreases progressively with size from 58.6% in medium sand (0.25 mm fraction); 51.6% in fine sand (0.149 mm), 45.2% in 0.074 mm and is about 40.2% in very fine
8 sand (0.062 mm) as recorded in table 4; Fig. 4). Garnet undergoes limited breaking during crushing of samples, perhaps due to lack of cleavage (Fig. 5 a). The broken grains as estimated under the microscope are about 8.9% in medium sand of 0.25 mm, 11.8% in 0.149 mm, 10.8% in 0.074 mm and 11.2% in very fine sand (0.062 mm) as shown in Table 5.

Three varieties of garnet are distinguished on the basis of colour and other optical characters. The colourless variety is most abundant and is closely followed by the light pink variety but the reddish brown variety is rather

38

Table 3: Average heavy mineral composition of diamictite and sandstone facies of Talchir Formation.

Sample No. / Mineralogy	JT1	JT2	JT3	JT12	JT19	Average
Garnet	58.95	62.86	47.99	62.59	12.35	48.95
Epidote	16.08	13.02	20.74	16.23	15.36	16.28
Zircon	04.17	04.66	02.95	00.54	10.90	04.64
Tourmaline	00.50	00.20	01.10	00.14	24.69	05.32
Rutile	00.24	00.29	00.12	00.93	02.69	00.85
Titanite	05.81	03.02	02.88	03.15	00.37	03.04
Muscovite & Chlorite	09.22	06.17	10.30	07.01	18.60	10.26
Amphiboles	00.62	02.63	05.74	05.22	07.01	04.24
Staurolite	00.86	00.38	-	-	-	00.24
Apatite	01.[illegible]	01.15	00.55	00.17	01.81	01.13
Opaques	01.45	05.56	07.55	03.92	06.13	04.92

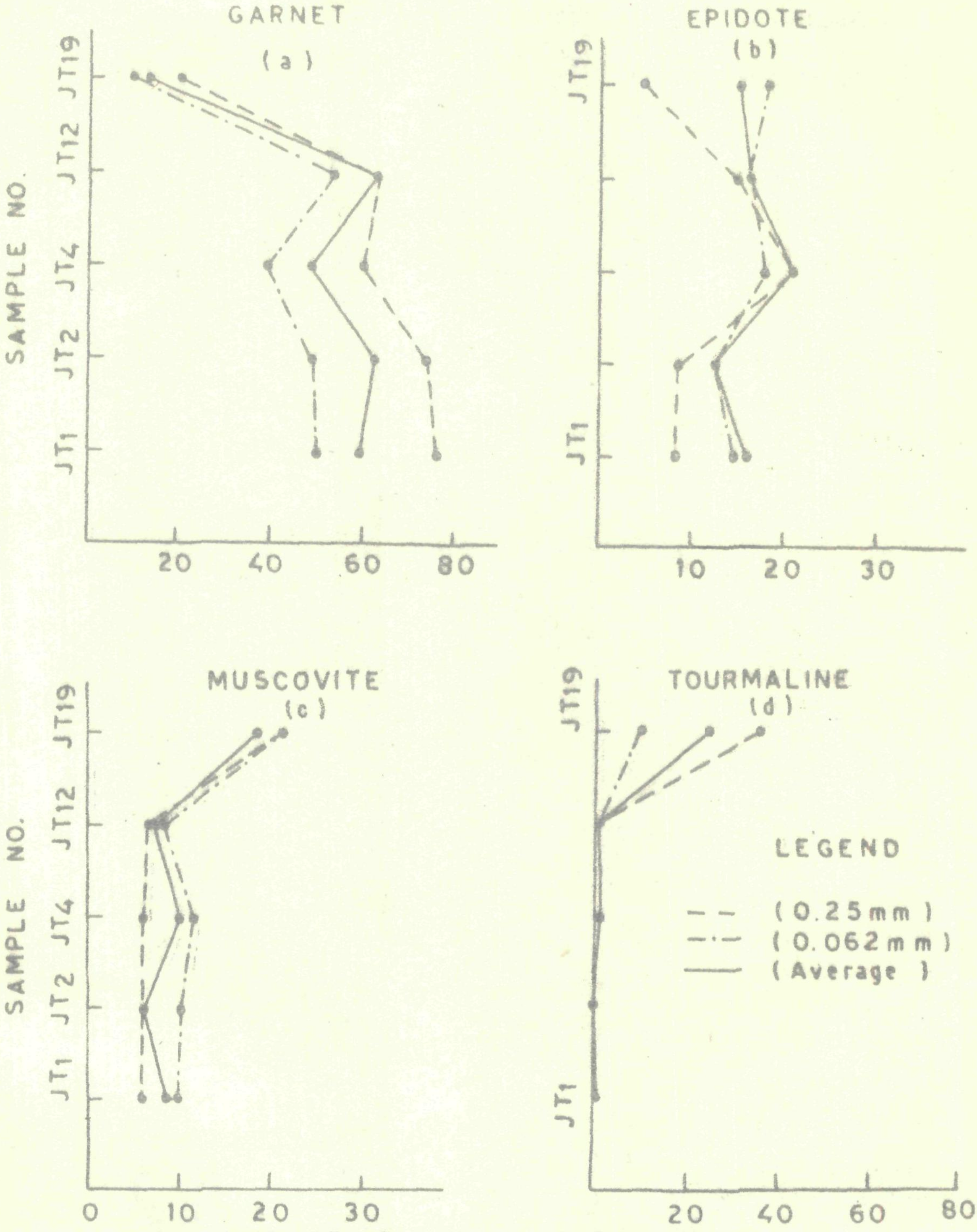


FIG. 4 : Graphs showing relative percentage of heavy mineral species from lower (JT 1) to upper (JT 19) parts of Talchir Formation and their variation from coarse (0.25 mm) to fine (0.062mm) fractions and average percentage.

rare. Grains are roughly equidimensional with surface showing concoidal fracture; those broken are sharply chipped (Plate 7a,b). Grains often show a pitted surface but etching effects are not uncommon. Grains are angular to subangular and sometimes even subangular to subrounded (Plate 7c,d,e) especially in upper Talchir, indicating by and large a direct derivation from crystalline source rocks without undergoing much reworking. Small euhedral grains of zircon, magnetite and quartz may occur as inclusions in garnet (Plate 7 e).

Colourless garnet may have been derived from metamorphosed limestone, schists and nephelene syenites. Pink garnet may have come from acid igneous rocks, e.g. granite, rhyolite; also low grade metamorphosed sediments. Red garnet may have come from igneous and metamorphic rocks, particularly crystalline gneisses and schists.

Epidote

Epidote varies from 20.7 to 13.0% as recorded in Table 3; Fig. 4b. By and large, it does not show any systematic variation stratigraphically, although its content is slightly more in basal than upper parts. The percentage of epidote

TABLE -4 : Average percentage of various heavy mineral species through different size fractions of sandstone/diamictite facies of Talchir Formation.

Size Fractions (mm)	0.25	0.149	0.074	0.062	Average
Mineralogy					
Garnet	58.61	51.63	45.24	40.27	48.93
Epidote	11.60	20.31	17.38	16.01	16.32
Tourmaline	7.41	5.25	6.48	2.16	5.32
Zircon	0.73	0.16	7.83	9.83	4.63
Rutile	0.53	0.87	1.22	0.59	0.80

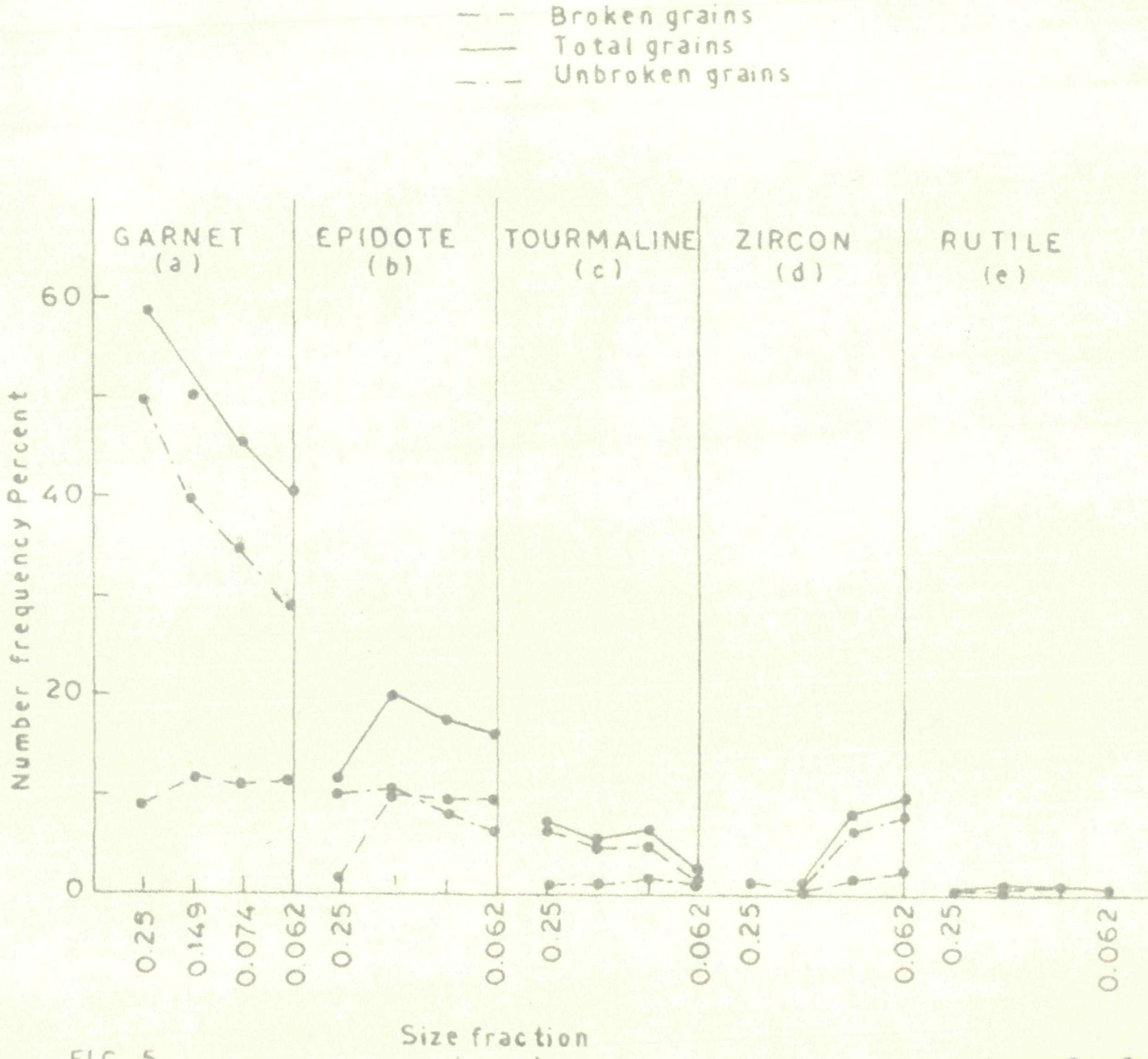


FIG. 5 : **Graphs showing relative percentage of various broken and unbroken "heavy" grains through different size fractions and their total percentage in Talchir Formation.**

varies considerably in different size fractions. Though, not systematic, its content varies from 11.6% in medium sand (0.25 mm), 20.3% in 0.149 mm, 17.3% (0.074 mm) to 16.0% in very fine sand (0.062 mm)(Table 4; Fig. 4b). The overall percentage of broken grains, however, increases from 1.8% in medium and (0.25 mm) to 9.5% in very fine sand (0.062) (Table 5; Fig. 5b).

Pistacite, zoisite and clinozoisite are the three varieties of epidote recognised in the given samples in which pistacite is most abundant. Pistacite is more common in basal part of the Talchir than upper. It is green in colour and show a weak but distinct pleochroism and high birefrengence. Grains of pistacite are equidimensional, subangular to subrounded, although subrounded to rounded grains are also present, particularly in the upper Talchir (Plate 7 f,g,h,i). Most of the grains show compass-needle interferance figures.

Zoisite is colourless showing prismatic form, normal polarisation colours of first order, and straight extinction. Grains are mostly subangular to angular.

PLATE - 7

Representative heavy mineral assemblage of Talchir diamictite and sandstone (0.25 - 0.062 mm grade)X75

a - e	Garnet
f - i	epidote
j	Muscovite
k	Tourmaline
l - o	Zircon
p	Actinolite


a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p

Clinozoisite is colourless to pale yellow, shows ultrablue anamolous polarization colours, and oblique extinction. Grains occur as columner aggregates and are subangular to angular.

Pistacite may have come from crystalline metamorphic rocks, originally rich in ferromagnesian minerls. Zoisite and clinozoisite may have been derived from crystalline schists and metamorphosed basic igneous rocks.

<u>Muscovite</u> (including Chlorite)

Detrital muscovite ranges from 10.3 to 6.1% in lower part but goes up to 18.6% in the upper Talchir (Table 3; Fig. 4c). Unlike other species, muscovite does not show any marked variation in different size fractions. Also, it was not possible to distinguish broken grains of muscovite from those unbroken.

This micaceous mineral is greyish to colourless (Plate 7j) and may occur as separate flakes or scaly aggregates.

Chlorite occurs in little amount (2%) out of total muscovite showing green colour, irregular shape and distinct pleochroism. It may show flaky nature at places. It is

TABLE - 5 : Average percentage of various broken and unbrokwn heavy mineral species through different size fractions of sandstone/diamictite facies of Talchir Formation.

Size Fractions (mm)	0.25		0.149		0.074		0.062			
Mineralogy	B	U	B	U	B	U	B	U	B	U
Garnet	8.91	49.70	11.86	39.77	10.84	34.40	11.27	29.00		
Epidote	1.87	9.73	9.88	10.43	9.39	8.0	9.49	6.52		
Tourmaline	6.48	0.93	4.62	0.63	4.95	1.53	1.34	0.82		
Zircon	0.62	0.11	0.16	-	1.62	6.12	2.21	7.62		
Rutile	0.0	0.53	0.26	0.61	0.57	0.65	0.23	0.36		

B = Broken Grains

U = Unbroken Grains

secondary and may occur as a pseudomorph after hornblende.

Detrital muscovite may have been derived from low grade schists (Folk, 1961).

Tourmaline

The percentage of tourmaline is appreciably low in the lower (0.2 to 1.1%) but increases rapidly in upper part (24.6%) (Table 3; Fig. 4d). It's amount, by and large, decreases progressively with size, such that it is about 7.4% in 0.25 mm, 5.2% in 0.149 mm, 6.5% in 0.074 mm and is only about 2.1% in very fine sand (0.062 mm) (Table 4; Fig. 4d). Breaking effect on tourmaline is more in coarse fraction (6.5% in 0.25 mm and 4.6% in 0.149 mm) and considerably less in the fine (4.9%, in 0.7 mm) and very fine sand (1.3%) (Table 5; Fig. 5c).

Four varieties of tourmaline distinguished on the basis of colour are brown, green, greenish brown and blue. Of these, the former two (brown and green) are more common than the latter (blue). Brown and green tourmaline occur usually in elongate form and prismatic shape (Plate 7k).

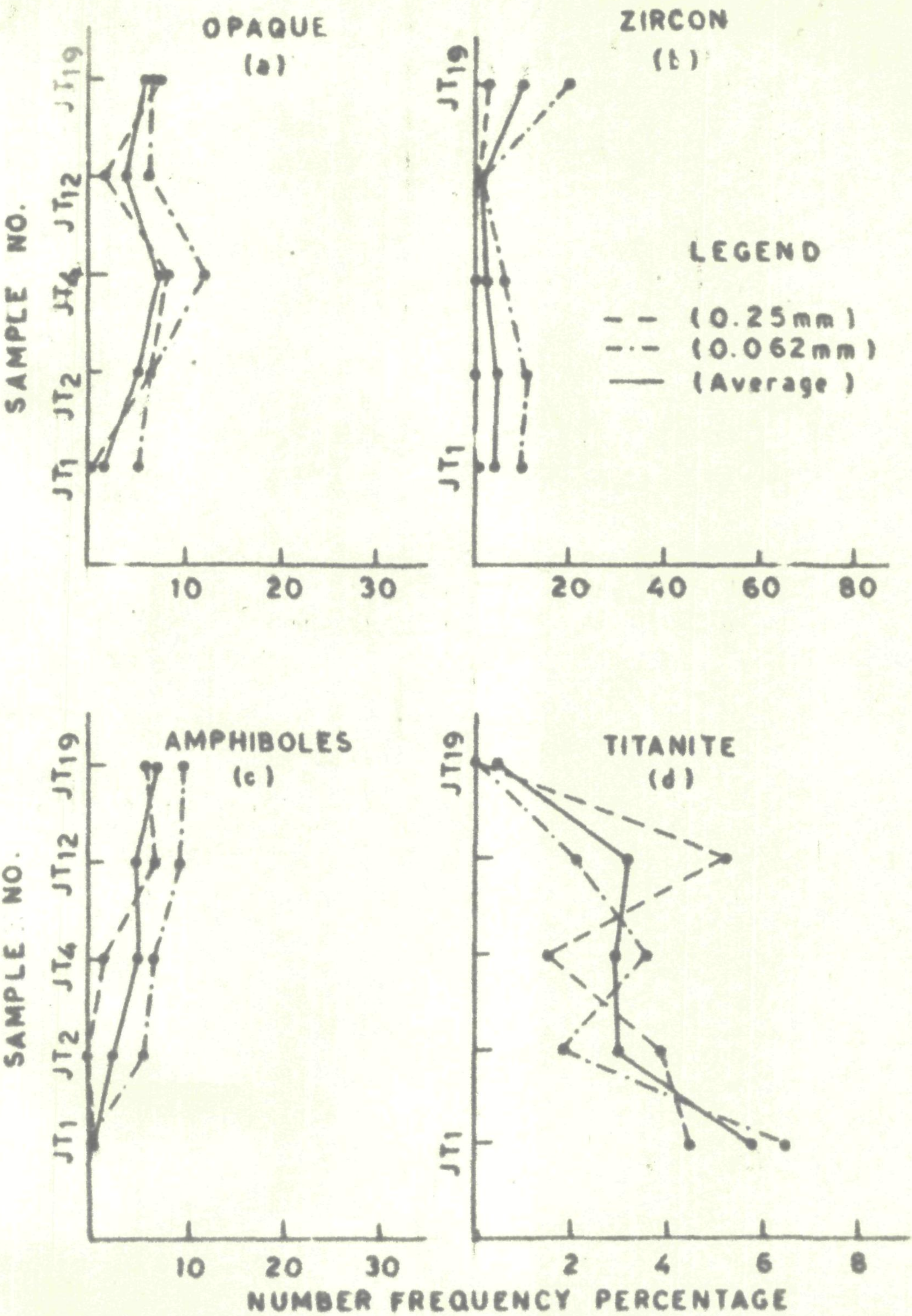


FIG. 6 : Graph showing relative percentage of heavy mineral species from lower (JT 1) to upper (JT 18) parts of Talchir Formation and their variation from coarse (0.25 mm) to fine (0.062mm) Fractions and average percentage.

Euhedral tourmaline may exhibit more or less subangular to subrounded edges and corners, giving signs of very little abrasion. Green and brownish green varieties are, however, subangular to angular, whereas blue tourmaline occuring in irregular shape, is angular. Mineral inclusion, particularly in brown tourmaline, are well rounded zircon, small needles of tourmaline and undifferentiated opaque minerals.

According to Krynine (1946), brown tourmaline is derived from pegmatised injected metamorphic terrains, green from granitic rocks and blue from pegmatites.

Zircon

Zircon content varies from 0.5 to 4.6% in the lower but rises to 10.9% in upper part (Table 3; Fig. 6b). It's amount rapidly increases as sediment size decreases so that zircon is estimated as 0.7% in 0.25 mm, 0.2% in 0.149 mm and about 7.8% in 0.074 mm to 9.8% in 0.062 mm as recorded in Table 4 Fig, 6b. Like garnet, zircon suffers minimal breaking during crushing of samples. Obviously, content of broken grains increases as sediment size decreases. It is 0.6% in medium sand, 0.2% (in 0.149 mm) and 1.6% (0.074 mm) to 2.2% (in 0.062 mm) (Table 5; Fig. 5d).

Three varieties of zircon are distinguished on colour basis: Dusty yellow, water clear, and pink. Dusty coloured zircon is most abundant; the other two varieties are also fairly common and occur in subequal amount. The mineral occurs commonly as elongated prismatic form with well defined pyramidal terminations, showing subangular grain outline

(Plate 7 lm). The equidimensional grains may show subrounded to rounded outline (Plate 7o). Some pink and dusty zircon grains may show very fine zoning (Plate 7 m,n). Authigenic overgrowth on detrital zircon may occur occasionally (Plate 7 l). Detrital zircon grains show every gradation from well defined crystal outline to well worn grains (Plate 7 l,m,n,o). Inclusions are common in pink and yellow varieties and consist of well rounded zircon, magnetite, rutile and fine dust (Plate 7 l,m).

Elongation ratio varies from 1.25 to 4.5

Amphiboles

The percentage of amphiboles varies from 0.6% to 5.7% in lower and goes upto 7.0% in upper part of the Talchir Formation (Table 3; Fig. 6c). Amphibole content increases systematically from coarse (3.0%) to fine (6.3%) fraction (Fig. 6c).

Two varieties of amphiboles occuring throughout the samples are actinolite and tremolite. Actinolite is light bluish green whereas tremolite is colourless. They occur as short prismatic crystals with perfect cleavage (Plate 7 p). Pleochroism is feeble but distinct. Grains are sharply angular, have a chipped appearance and many of them show etching effects especially at the edges. Hornblende occurs rarely in a few samples. Some altered grains of chlorite are also present which are supposed to be pseudomorph after hornblende.

Actinolite and tremolite may have been derived directly from crystalline schists, granular or massive metamorphic rocks, or even secondary alteration products of ferromagnesian silicates in igneous rocks. Tremolite may also be derived from disintegration of serpentine.

Titanite

Titanite ranges from 2.8 to 5.8% in lower Talchir, but abruptly decreases and is as low as 0.37% in upper Talchir (Table 3, Fig. 6d). By and large titanite decreases from 3.0% in coarse (0.25 mm) to 2.8% in fine fraction (0.062 mm) (Fig. 6d).

Titanite is marked by light brown colour and weak pleochroism. Most of the grains are euhedral in shape but irregular grains may also present. They are commonly angular to subangular. Unidentified inclusions of needle like minerals may occur in titanite.

Titanite may have been derived from granites, intermediate igneous rocks, gneisses and schists.

Rutile

Rutile occurs in small amount in almost all the samples. It is less than 1% in lower Talchir and upto 2.7% in upper Talchir (Table 3). The overall relative percentage of broken grains increases from coarse to fine fraction (Table 5).

Rutile is characterised by brown to reddish colour and high relief. They are generally angular to subangular, lacking evidence of abrasion. Rutile is derived commonly

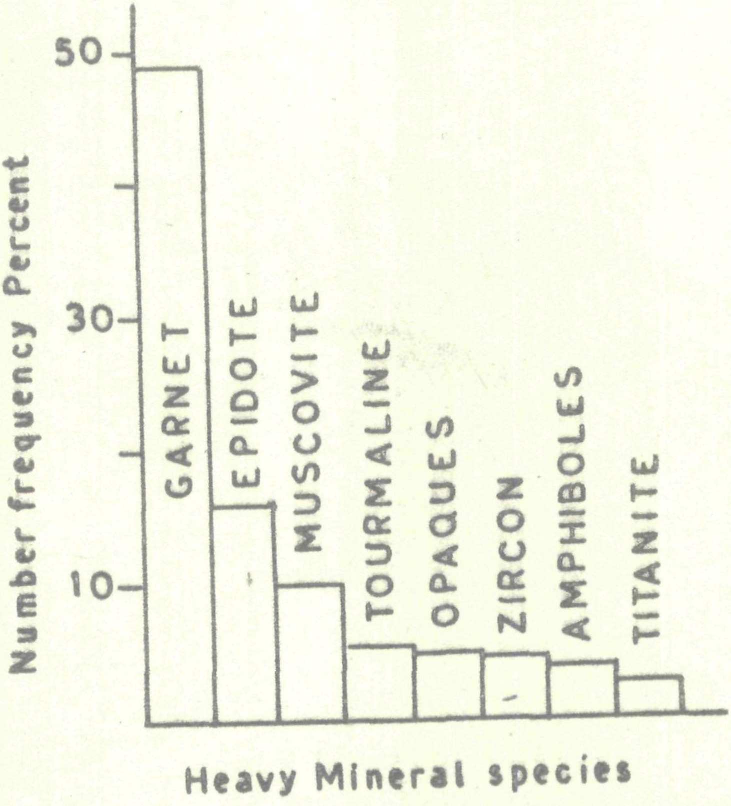


FIG. 7 : Bar diagram showing frequency distribution of various heavy minerals in Talchir Formation.

from acid igneous rocks and crystalline metamorphic rocks.

Opaques

The amount of opaque mineralss varies from 1.4 to 7.5%, and like most non opqques increase from coarse to fine fractions(Fig.6a).

Among the opaques, both, magnetite and ilmenite are present. Magnetite is much more common and recognised by steel grey colour and metallic lustre. Grains are angular to subangular. Ilmenite occurs as irregular grains of brownish colour.

Opaque minerals (magnetite and ilmenite) may have been derived from basic and ultrabasic igneous rocks.

Apart from the minerals described above, staurolite and apatite may also occur as accessory minerals in the Talchir Formation.

The bar diagram in Fig. 7 shows the frequency distribution of heavy minerals in Talchir rocks of the given area.

Barakar Formation

Sandstones in the Barakar Formation exhibit a marked decline in the amount of garnet and epidote, and corresponding increase in the amount of tourmaline, muscovite and opaque minerals, as compared to those found in Talchir Formation.

Also some mineral species show an improvement in roundness upto certain extent. Sailent characters of different heavy minerals of Barakar sandstones are as follows in order of abundance.

Muscovite

Muscovite varies from 17.5 to 34.2% (Table 6). In general, it's percentage increases from coarse to fine fraction (Fig. 8). Muscovite shows similar character as in the Talchir.

Tourmaline

Tourmaline varies on an average from 19.4 to 24.6% in the given samples (Table 6). It's amount varies in different size fractions from 15.9% (0.25 mm) through 27.9% (0.149 mm) and 20.1% (0.074 mm) to 19.4% (0.062 mm) (Table 7; Fig. 8c). Of these, the relative percentage of broken grains is 14.5%, 25.3%, 17.8% and 17.1%, respectively in 0.25 mm, 0.149 mm, 0.074 mm and 0.062 mm size fractions, (Table 8; Fig. 9c) implying that bulk of the tourmaline grains have suffered breaking during the crushing of sample.

Tourmaline is of brown, yellow, pink, green and blue varieties, of which the first four varieties are more common. Brown, yellow and pink tourmalines show both light and deep shades. Green tourmaline occurs in three different species showing pleochroism from dark green to almost black,

Table 6 : Average heavy mineral composition of sandstone facies of Barakar Formation

Sample No.	JB 2B	JB 5	JB 6	JB 9	JB 11B	Average
Mineralogy						
Garnet	01.27	02.82	00.61	10.53	19.67	06.98
Zircon	04.47	06.42	05.61	05.63	05.15	05.45
Tourmaline	24.67	19.85	19.42	16.79	23.81	20.90
Muscovite	25.20	34.10	21.23	17.49	20.89	23.78
Biotite	00.00	00.41	00.07	00.14	00.40	00.20
Epidote	10.20	09.78	23.75	06.01	03.76	10.70
Rutile	03.78	01.03	01.74	00.95	01.36	01.77
Opaques	21.23	18.57	25.93	36.68	22.85	25.05
Anatase	-	00.22	-	01.15	00.09	00.29
Chlorite	03.25	02.42	00.03	02.53	01.31	01.90
Trem/act	05.52	02.80	00.96	01.76	00.61	02.33
Titanite	00.33	01.45	00.24	00.24	-	00.45

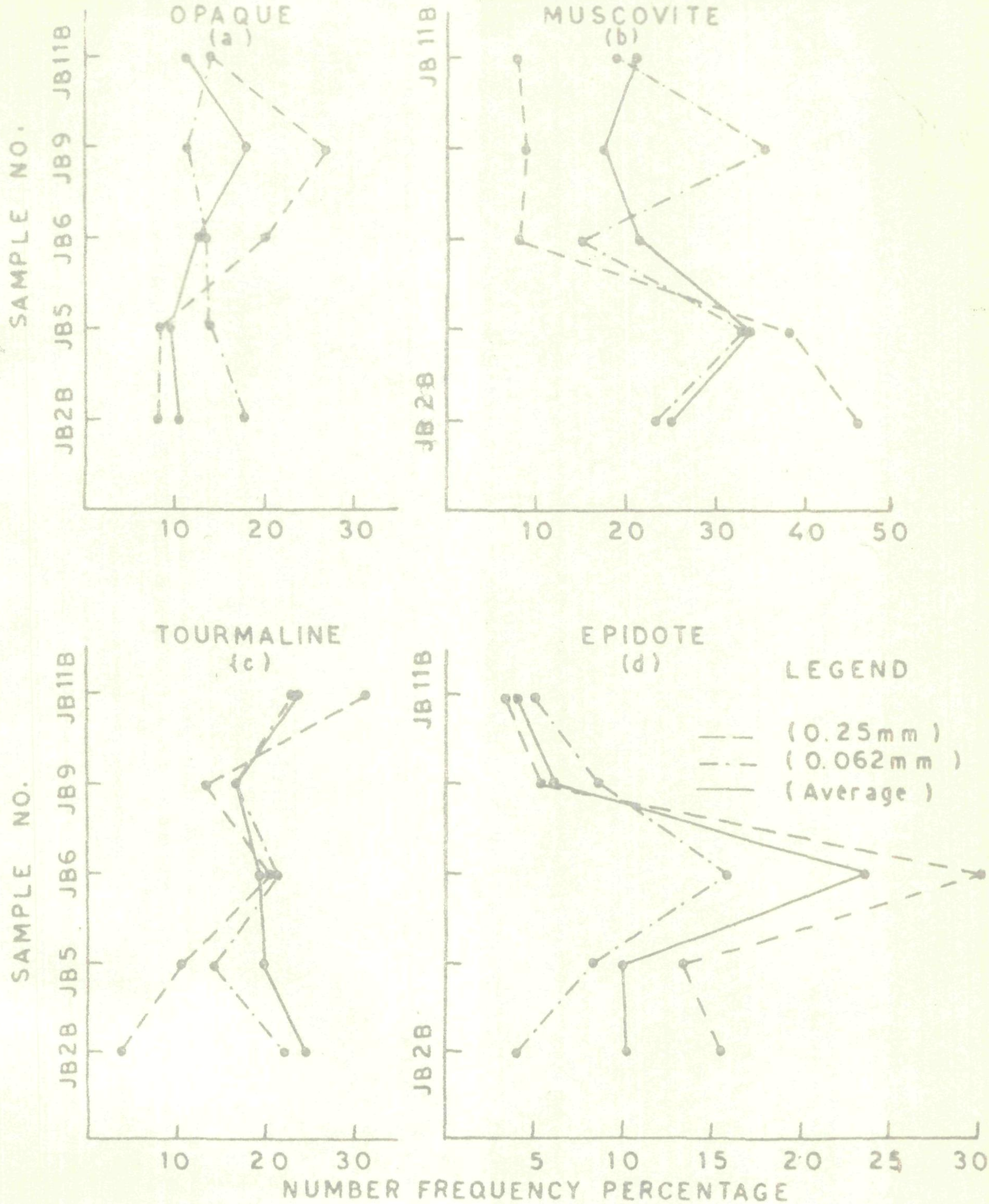


FIG. 8

: Graph showing relative percentage of heavy mineral species from lower (JB 2B) to upper (JB 11B) parts of Barakar Formation and their variation from coarse (0.25 mm) to fine (0.062 mm) fractions and average percentage.

green to dark green, and colourless to green.

The mineral occurs in various forms, the common being prismatic grains bounded by rhombohedra (Plate 8b, d,e,f), all traversed by irregular fractures. Pseudohexagonal grains are also present. Authigenic overgrowth on detrital tourmaline may occur occasinnally (Plate 8f). In certain cases, the edges of prismatic grains are rounded (Plate 8d). Inclusions are common in tourmaline, and are mostly of magnetite, zircon and rounded tourmaline.

Epidote

Epidote ranges from 9.7 to 23.7% in lower Barakar and goes down to 3.7 in a few samples of upper Barakar (Table 6; Fig. 8d). The percentage in different size fractions varies from 11.6% (in 0.25 mm) through 20.3% (in 0.149 mm) and 17.4% (in 0.074 mm) to 16.0% (in 0.062 mm) (Table 7; Fig. 8d). Epidote grains have suffered breaking to the extent of about 7.8% out of 11.6% in medium sand fraction (0.25 mm), 6.8% out of 20.3% in fine sand (0.149 mm) and about 6.0% out of 16 - 17% in very fine sand fractions (.074 and.062 mm) (Table 8; Fig. 9b).

Among the species of epidote, pistacite is more common than zoisite and clinozoisite. They are subangular to subrounded. Species of epidote are similar in characters to those recognised in the underlying Talchir Formation.

TABLE- 7 : Average percentage of various heavy mineral species through different size fractions of sandstone facies of Barakar Formation.

Size Fractions (mm)	0.25	0.149	0.074	0.062	Average
Mineralogy					
Garnet	8.49	9.60	7.10	2.74	6.98
Epidote	13.39	11.28	9.74	8.39	10.70
Tourmaline	15.89	27.98	20.18	19.42	20.86
Zircon	2.45	2.04	8.08	9.24	5.45
Rutile	1.97	2.69	1.46	0.94	1.76

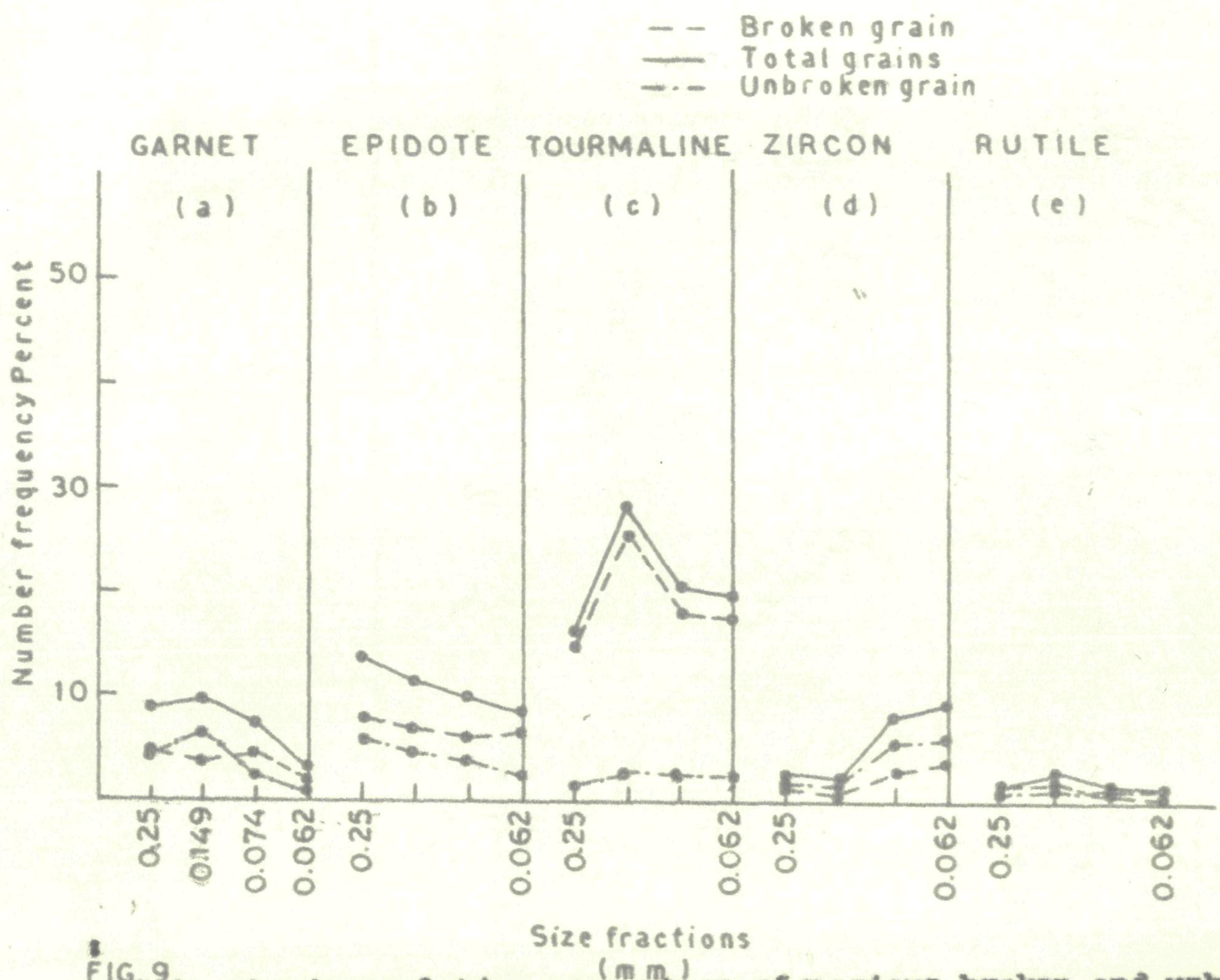


FIG. 9
Graph showing relative percentage of various broken and unbroken "heavy" grains through different size fractions and their total percentage in Barakar Formation.

Garnet

Unlike Talchir, the amount of garnet is as low as about 0.6 to 2.8% in the samples of lower Barakar but in some samples of the upper Barakar, garnet content increases up to 19.6% (Table 6 ; Fig. 10 a). However, like Talchir garnet content is more (~ 9.0%) in medium sand fraction (0.25 mm) and is relatively less (2.7%) in very fine sand fraction (Table 7; Fig. 10 a). The relative percentage of broken grains also decreases from coarse to fine fraction and varies from 4.5% (in 0.25 mm) through 3.6% (in 0.149 mm) and 4.5% (in 0.074 mm) to 2.0% (in 0.062 mm) (Table 8; Fig. 9 a).

Garnet comprising of colourless, pink and reddish brown varieties is similar in characters to those recognised in the underlying Talchir Formation.

Zircon

Detrital zircon increases from 2.45% in medium sand fraction (0.25 mm) to 9.24% in very fine sand size (0.062 mm) (Table 7; Fig. 10 b). Also, relative percentage of broken grains increases from coarse (1.0%) to fine fraction (3.6%) (Table 8; Fig, 9d).

Zircon occurs in some six varities: water clear, dusty, yellow, brown, pink and green. The first two varieties are very common others less so. Among optical characters, noteworthy

TABLE- 8 : Average percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Barakar Formation.

Size Fractions (mm)	0.25		0.149		0.074		0.062	
Mineralogy	B	U	B	U	B	U	B	U
Garnet	4.52	3.97	3.60	6.0	4.59	2.51	2.06	0.68
Epidote	7.85	5.54	6-83	4.85	6.18	3.56	6.25	2.14
Tourmaline	14.48	1.41	25.35	2.63	17.82	2.36	17.16	2.26
Zircon	1.09	1.36	0.54	1.5	2.71	5.37	3.60	5.64
Rutile	1.5	0.47	1.86	0.83	0.48	0.98	0.30	0.64

B = Broken Grains

U = Unbroken Grains

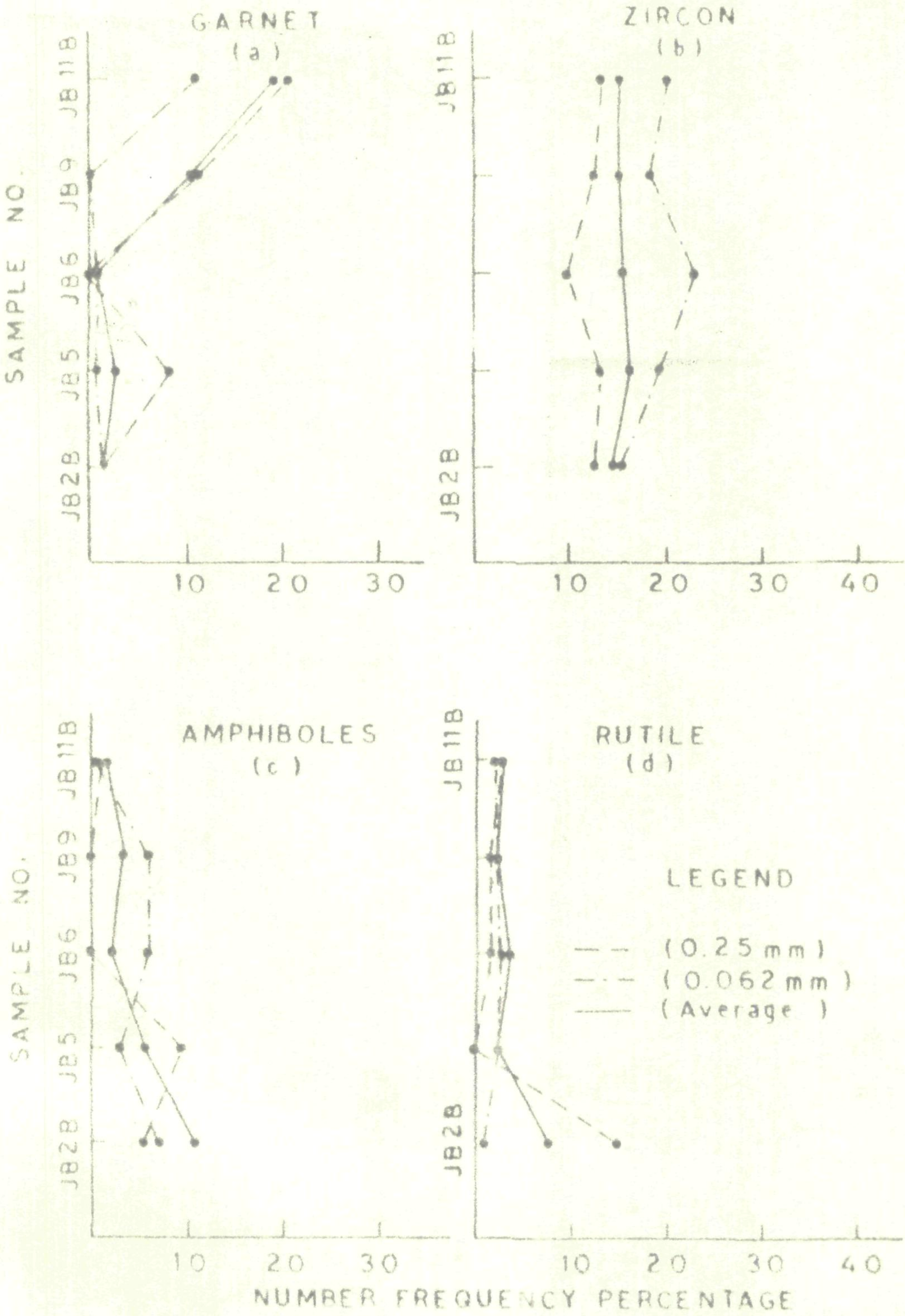


FIG 10 : **Graph showing relative percenta ge of heavy mineral species from lower (JB 2B) to upper (JB 11B) parts of Barakar Formation and their variation from coarse (0.25 mm) to fine (0.062mm) fractions and average percentage.**

are as follows: Brown and yellow zircon may show beautiful zoning (Plate 8i); dark brown zircons are slightly pleochroic; green zircon is free from zoning and inclusions. Common inclusions are those of rounded zircon, opaque minerals, glassy material and rutile needles (Plate 8g,h,i,j,k).

Elongation ratio ranges commonly from 1.25 to 4.25 and goes maximum upto 5.25.

Rutile

Rutile varies from 1.0 to 3.7% (Table 6). It's content is relatively more (1.9%) in coarse fraction (0.25 mm) and less (0.9%) in fine fraction (0.062) (Table 7; Fig. 10d) so is the property of broken grains (Table 9; Fig. 9e).

It is foxy red, yellow and reddish brown. The first one is more common than the second; the third variety is comparatively rare and may be represented by one or two grains in a given sample. The mineral usually occurs as prismatic grain with crude pyramidal terminations which are often rounded. Yellow and reddish brown varieties usually occur as anhedral fractured grains. Diagonal strations are commonly present on foxy red and yellow varieties.

Other Minerals

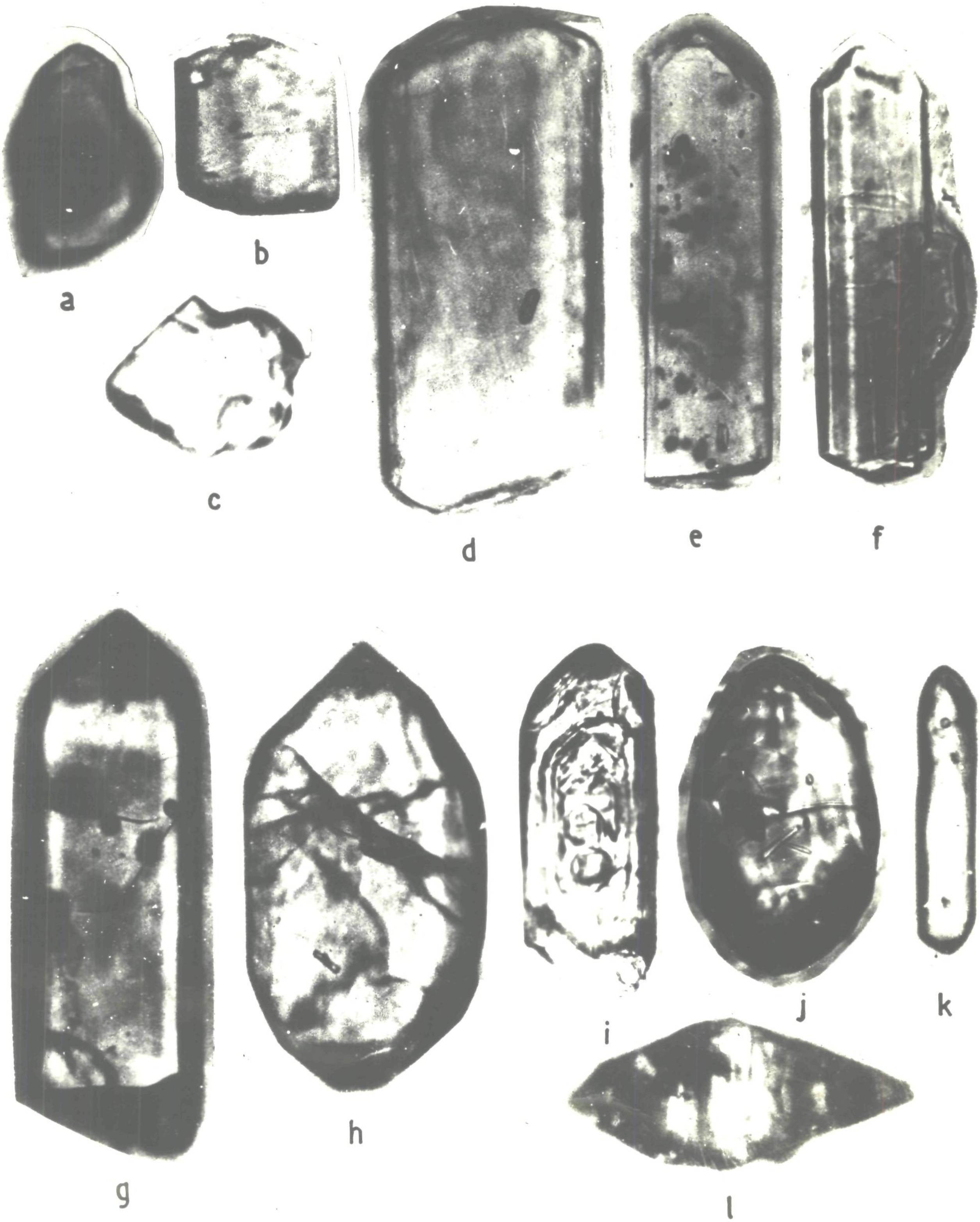
These include tremolite-actinolite, anatase, titanite (sphene) and chlorite.

PLATE - 8

Representative heavy mineral assemblage of Barakar sandstone (0.25 - 0.062 mm grade) X 75

a, b, d, e, & f	Tourmaline
c	Garnet
g - k	Zircon
l	Titanite (sphene)

Plate 8



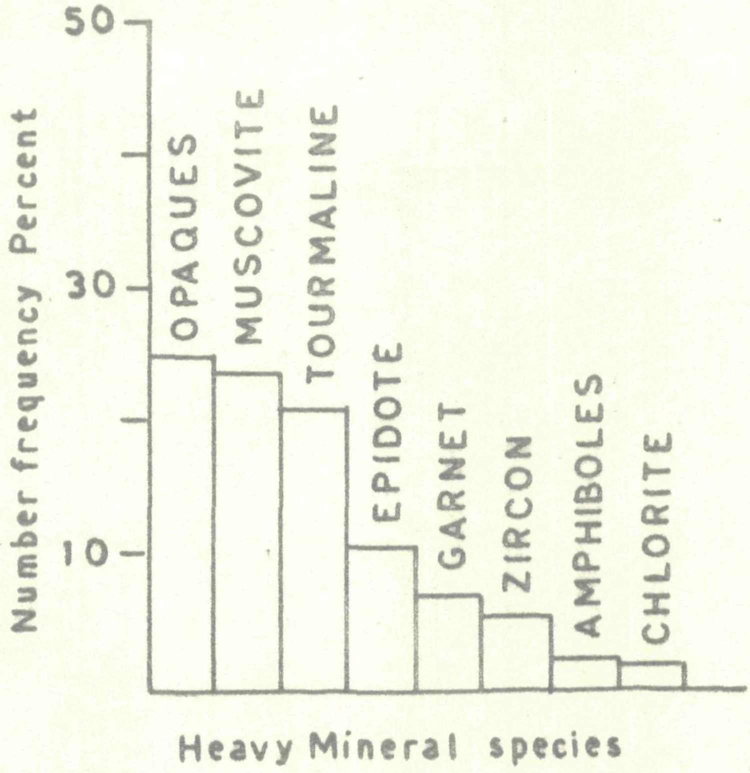


FIG. 11 : Bar diagram showing frequency distribution of various heavy minerals in Barakar Formation.

Tremolite-actinolite vary from 1.0 to 5.5% in lower to about 0.6% in upper part (Table 6), and show the same characters as in Talchir.

Anatase constitutes minor amount and is always less than one percent. It is yellowish green to green in colour, sometimes blue.

Titanite (Sphene?) (Plate 81) and secondary chlorite may present rarely ($<$ 1.0%) (Table 6).

Opaques

The percentage of opaques varies from 18.5 to 36.6% (Table 6). Among these minerals, magnetite is more common than ilmenite, both showing common characters to those of Talchir Formation.

The bar diagram in Fig. 11 shows the frequency distribution of heavy minerals in Barakar rocks.

Barren Measures

Heavy mineral species in the Barren Measures are almost same as recorded in the underlying Talchir and Barakar Formations, though their relative percentages may vary in different formations. For example, garnet content which decreases in the Barakar Formation is again well reported in the Barren Measures (Table 9). Roundness of all the minerals,

Table 9 : Average heavy mineral composition of sandstone facies of Barren Measures.

Sample No.	8/2	7/12	7/9	6/6	6/2	Average
Mineralogy						
Zircon	07.25	05.20	08.02	09.47	06.65	07.31
Tourmaline	14.74	16.92	15.65	19.65	16.70	16.73
Rutile	01.11	00.09	01.21	01.41	00.33	00.99
Garnet	24.13	38.81	40.59	07.55	05.98	23.41
Epidote	06.53	08.04	10.14	16.15	10.00	10.17
Muscovite	20.96	09.26	08.89	13.86	22.52	15.09
Chlorite	02.74	03.87	03.68	01.15	03.83	03.05
Opaques	19.41	16.94	11.50	29.04	29.56	21.36
Trem/act	01.17	-	-	01.05	02.42	00.93
Anatase	00.13	-	00.25	00.26	01.94	00.52
Staurolite	00.13	-	-	-	-	00.03

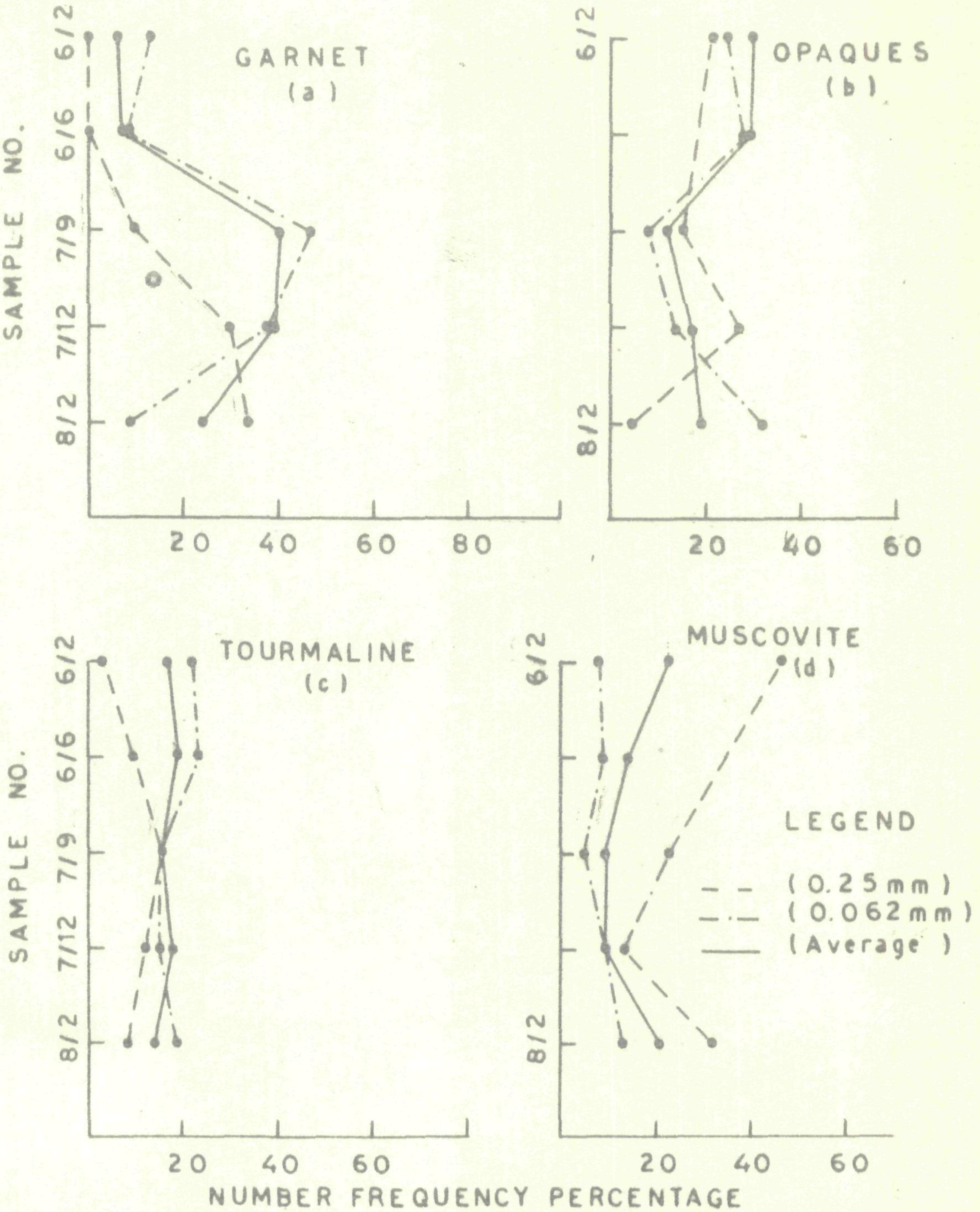


FIG. 12: Graph showing relative percentage of heavy mineral species from lower (8/2) to upper (6/2) parts of Barren Measures and their variation from coarse (0.25 mm) to fine (0.06 mm) fractions and average percentage.

by and large, improves further.

The description of different heavy species is given below:

Garnet

Garnet varies from 24.1 to 45.5% in the lower part and is as low as 5.9% in some samples of the upper part (Table 9; Fig.12 a). It's percentage, in different size fraction varies from 18.5% through 28.4% and 25.6% to 23.1%, respectively, in medium sand (0.25 mm), fine sand size (0.149 mm) and very fine sand size (0.074 and 0.062 mm) (Table 10; Fig. 12 a).

The relative percentage of broken grains increases from coarse (5.8%) to fine (14.7%) fractions (Table 11; Fig.13a)). ld

Colourless garnet is most common, followed by pink variety, Dusty garnet is rather rare. Garnets are commonly etched; though some of them do not show etching. They are commonly equidimensional but oblate grains may also present. Inclusions of well rounded zircon are very common in garnet. Sp

Tourmaline

Sp Tourmaline ranges from 14.7 to 19.6, and increases systematically in different size fractions from 10.2% (in 0.25 mm) add through 17.0% (0.149 mm) and 18.6% (0.074 mm) to 19.0% (0.062 mm) (Table 10; Fig. 12 c). High percentage of broken

TABLE-10 : Average percentage of various heavy mineral species through different size fractions of sandstone facies of Barren Measures.

Size Fractions (mm)	0.25	0.149	0.074	0.062	Average
Mineralogy					
Garnet	18.54	28.47	25.68	23.15	23.96
Epidote	11.39	8.36	10.49	10.79	10.25
Tourmaline	10.26	17.04	18.66	19.08	16.26
Zircon	2.36	1.17	11.48	18.99	7.25
Rutile	0.22	0.92	1.03	1.54	0.93

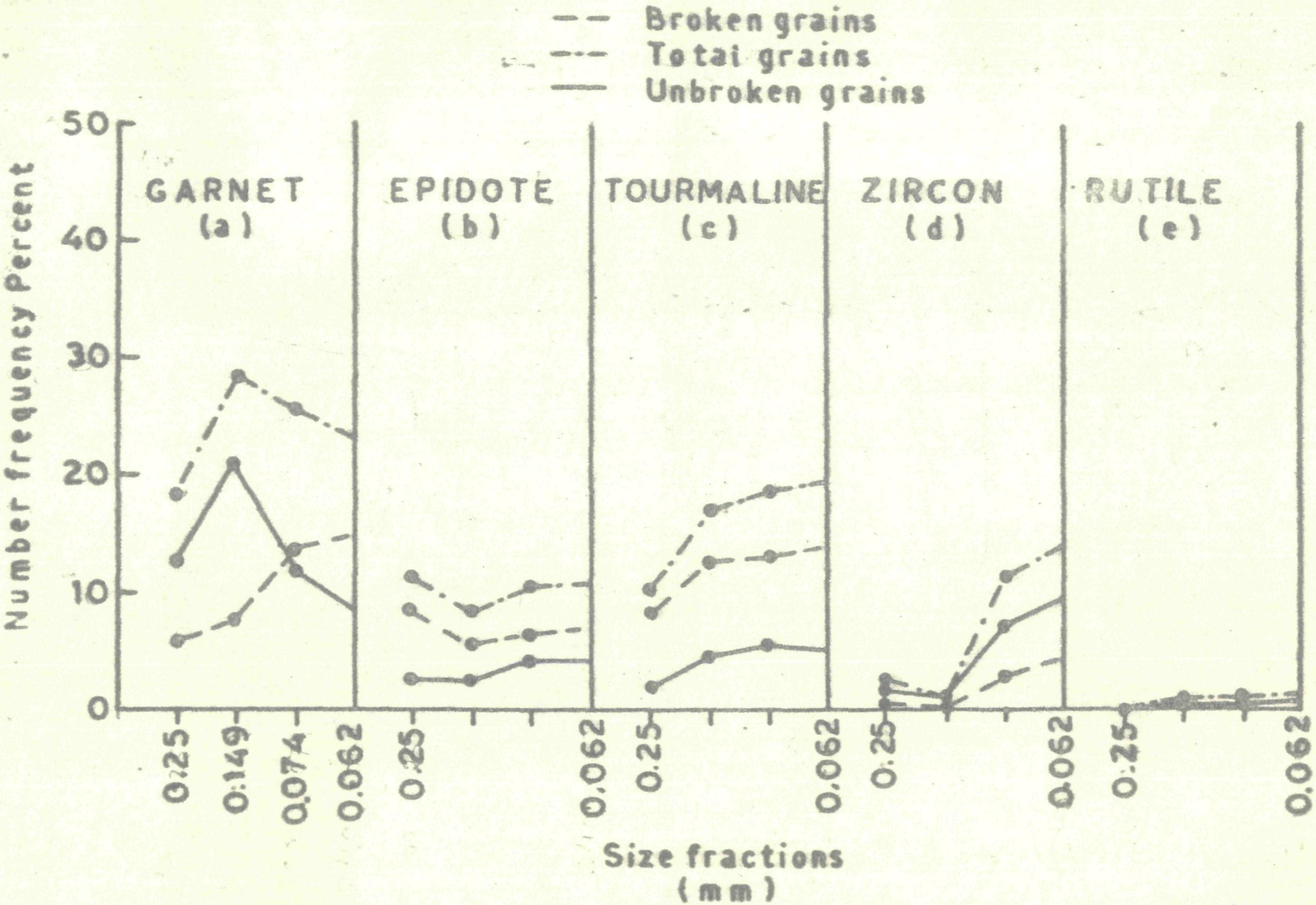


FIG. 13. Graph showing relative percentage of various broken and unbroken "heavy" grains through different size fractions and their total percentage in Barren Measures.

grains of tourmaline in fine to very fine sand fractions (12.9% and 13.8%), implies their derivation from crushing of coarser grains (Table 11; Fig. 13c).

Brown and green tourmaline occur in both light and dark shades. Green tourmaline occurs in three different species as in the Barakar Formation. Blue tourmaline is present rarely. Commonly tourmaline shows similar characters to those of underlying Barakar, except it is subrounded to rounded, though few euhedral grains may also occur (Plate 9c,d,f).

Muscovite

Muscovite is fairly well represented in Barren Measures, ranging from 8.8 to 22.5 percent (Table 9), though not so abundant as in the Barakar. Unlike Talchir and Barakar, muscovite content decreases systematically from coarse to fine fraction (Fig. 12d). Flakes of muscovite closely resemble those noted in the underlying formations (Plate 9g).

Epidote

As in the Talchir, epidote widely occurs irrespectively of grains size, ranging from 6.5 to 16.1 percent (Table 9) The relative percentage of broken grains vary from 8.5% (0.25 mm) through 5.8% (0.149 mm) and 6.5% (0.074 mm) to 6.8% (0.062 mm) (Table 11; Fig. 13b).

Epidote occurs in green, yellowish green, colourless and brownish varieties; the latter variety is rather rare, TABLE - 11: Average percentage if various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Barren Measures.

Size Fractions (mm)	0.25		0.149		0.074		0.062	
Mineralogy	B	U	B	U	B	U	B	U
Garnet	5.86	12.66	7.74	20.73	13.68	12.0	14.70	8.45
Epidote	8.48	2.91	5.80	2.56	6.50	3.99	6.83	3.96
Tourmaline	8.33	1.93	12.59	4.48	12.99	5.67	13.87	5.21
Zircon	0.42	1.94	0.15	1.02	3.05	7.26	4.46	9.53
Rutile	0.0	0.22	0.38	0.54	0.49	0.54	0.79	0.75

B = Broken Grains

U = Unbroken Grains

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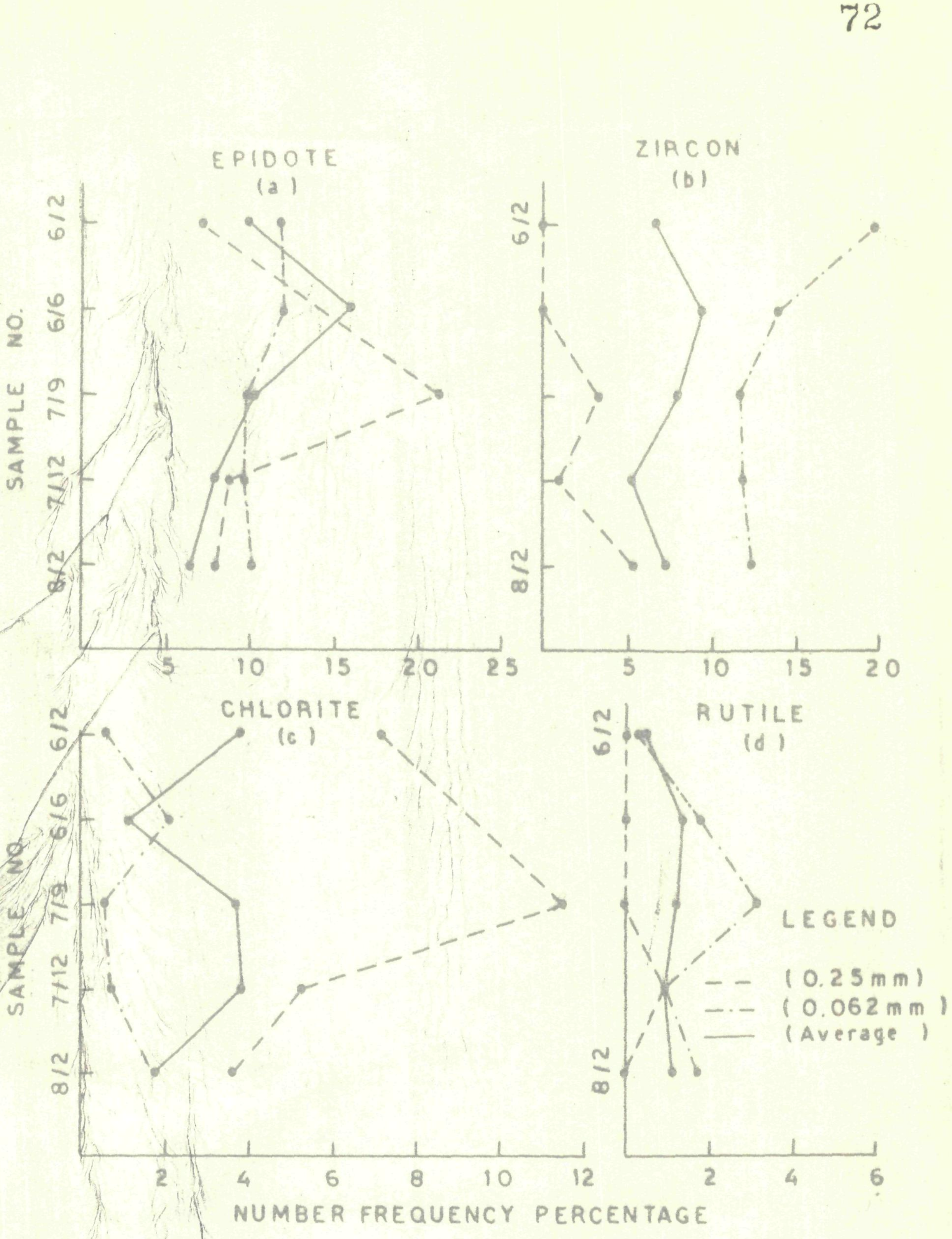


FIG. 14 : Graph showing relative percentage of heavy mineral species from lower (8/2) to upper (6/2) parts of Barren Measures and their variation from coarse (0.25 mm) to fine (0.06 mm) fractions and average p percentage.

add Coloured varieties are generally subrounded to rounded whereas
add colourless variety is subangular to angular. Generally speaking
epidotes show same general characters as in the underlying formations.

Zircon

Zircon varies from 5.2 to 9.4 percent. It's content increases from coarse to fine fraction varying from 2.3% in 0.25 mm, 11.5% in 0.074 mm to 13.9% in o.062 mm size fractions (Table 10; Fig. 14b). Like tourmaline, broken grain of zircon are more (3 to 4.5%) in fine than the coarser size (0.2 - 0.4%) as recorded in Table 11; Fig. 13d.

It's species on the basis of colour are no different than those recorded earlier. Dusty zircon is most abundant followed by colourless and pink varieties. Pinkish green variety which is fairly common shows slight pleochroism from pink to pale green. Grains are mostly subrounded to rounded (Plate 9 h,i). Zoning in the dusty and pink varieties is not
add so common as in the Barakar and Talchir. Authigenic overgrowth may be present on partly abraided grains.

Elongation ratio ranges from 1 to 3.7 and be as high as 6.5 in few grains.

Other Non Opaque Minerals

They include chlorite (1-3.8%), rutile (0.3 - 1.4%),

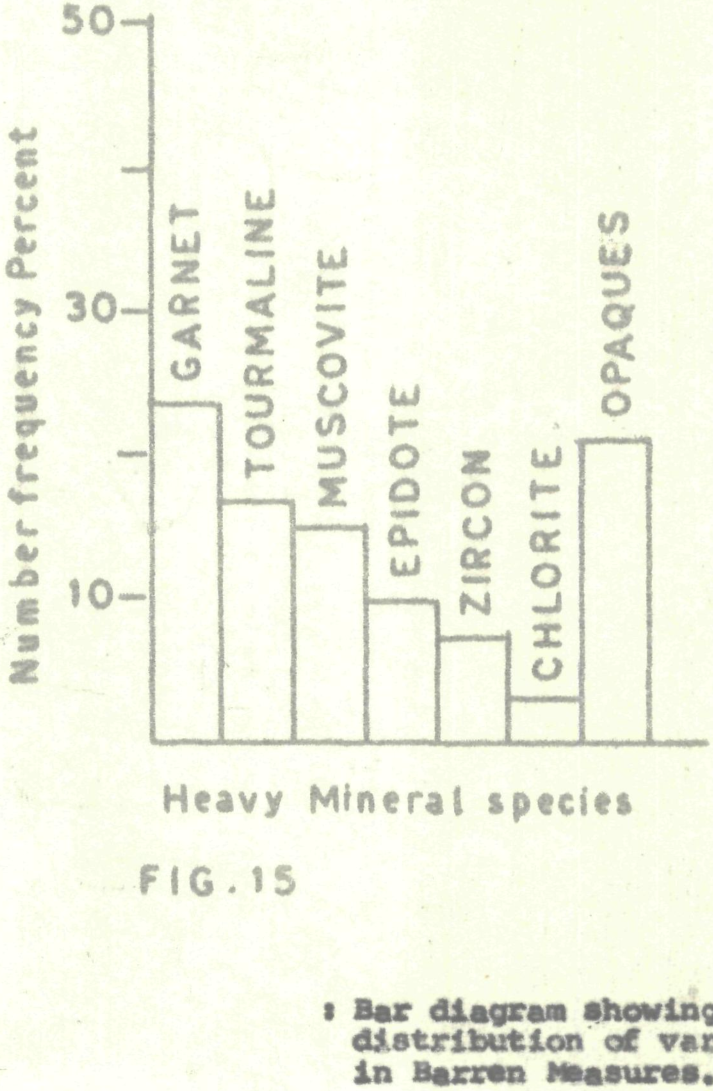


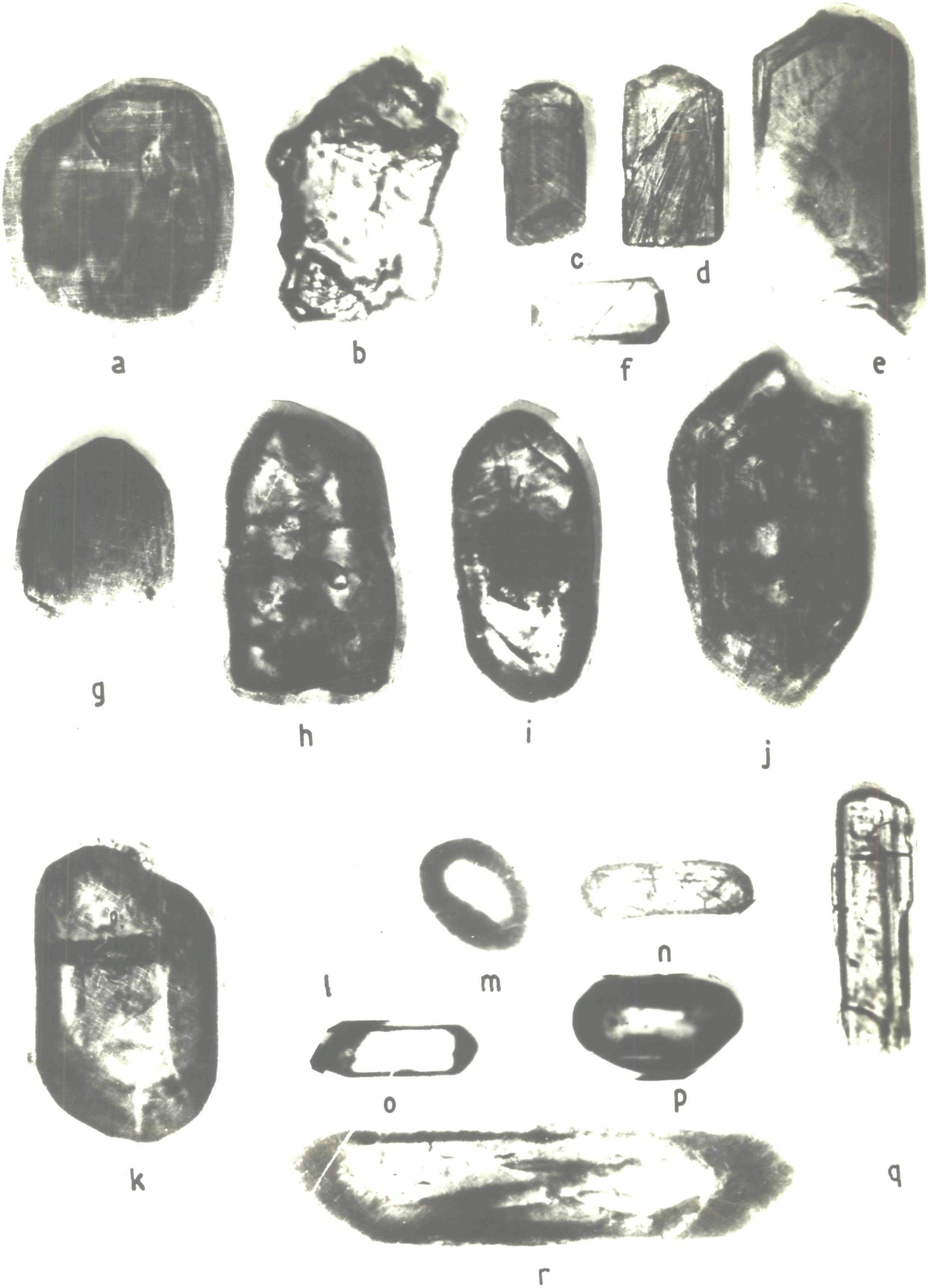
FIG.15

: Bar diagram showing frequency distribution of various heavy minerals in Barren Measures.

PLATE- 9

Representative heavy mineral assemblage of Barren Measures and Ranigajn sandstones (0.25 - 0.062 mm grade) X 75

a - b	Garnet (Raniganj)
c,d, & f	Tourmaline (Barren Measure)
e	Tourmaline (Raniganj)
g	Muscovite (Barren Measure)
h - i	Zircon (Barren Measure)
j - p	Zircon (Raniganj)
q	Tremolite (Barren Measure)
r	Rutile (Raniganj)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tremolite-actinolite (1-2.4%) (Plate 9q), anatase (0.00-2.0%) and staurolite (0.0 - 0.13%), exhibiting general characters similar to those noted in the underlying formations.

Opaques

Opaque minerals vary from 11.5 to 19.4% in the lower and goes up to 29.5% in upper part (Fig. 12b). Grains are rounded to well rounded and show the same common characters as described earlier.

The bar diagram in Fig. 15 shows the frequency distribution of heavy minerals in Barren Measures.

Raniganj Formation

In the Raniganj Formation, the percentage of garnet increases abruptly, so does the percentages of zircon and rutile, whereas epidote and opaques decrease considerably (Table 12). Majority of grains do not show marked difference in roundness as compared to those of underlying Barren Measures. The description of various mineral species is given below:

Garnet

Garnet registers a rapid increase from 31.3 to 67.1% in sandstones of Raniganj Formation (Table 12). It is as high as about 50.8% to 57.3% in medium to fine sand fractions. unlike tourmaline, garnet breaks as to a limited extent,

Table 12 : Average heavy mineral composition of sandstone facies of Raniganj Formation

Sample No.	JR 16	JR 14	JR 28	JR 1	JR 2	Average
Mineralogy						
Garnet	31.05	59.12	67.19	46.45	31.33	47.02
Zircon	16.05	12.18	08.11	09.95	14.36	12.13
Tourmaline	22.27	03.92	07.29	16.52	14.43	12.88
Rutile	04.98	04.01	03.52	03.78	03.49	03.96
Muscovite & Chlorite	17.62	09.96	04.05	11.67	18.77	12.41
Biotite	00.94	02.26	00.52	00.74	00.67	01.02
Epidote	02.31	02.30	01.27	02.59	03.17	02.33
Opaques	04.72	05.78	07.70	07.96	13.70	07.97
Apatite	-	00.14	-	-	-	00.02
Anatase	-	00.13	-	00.12	-	00.05

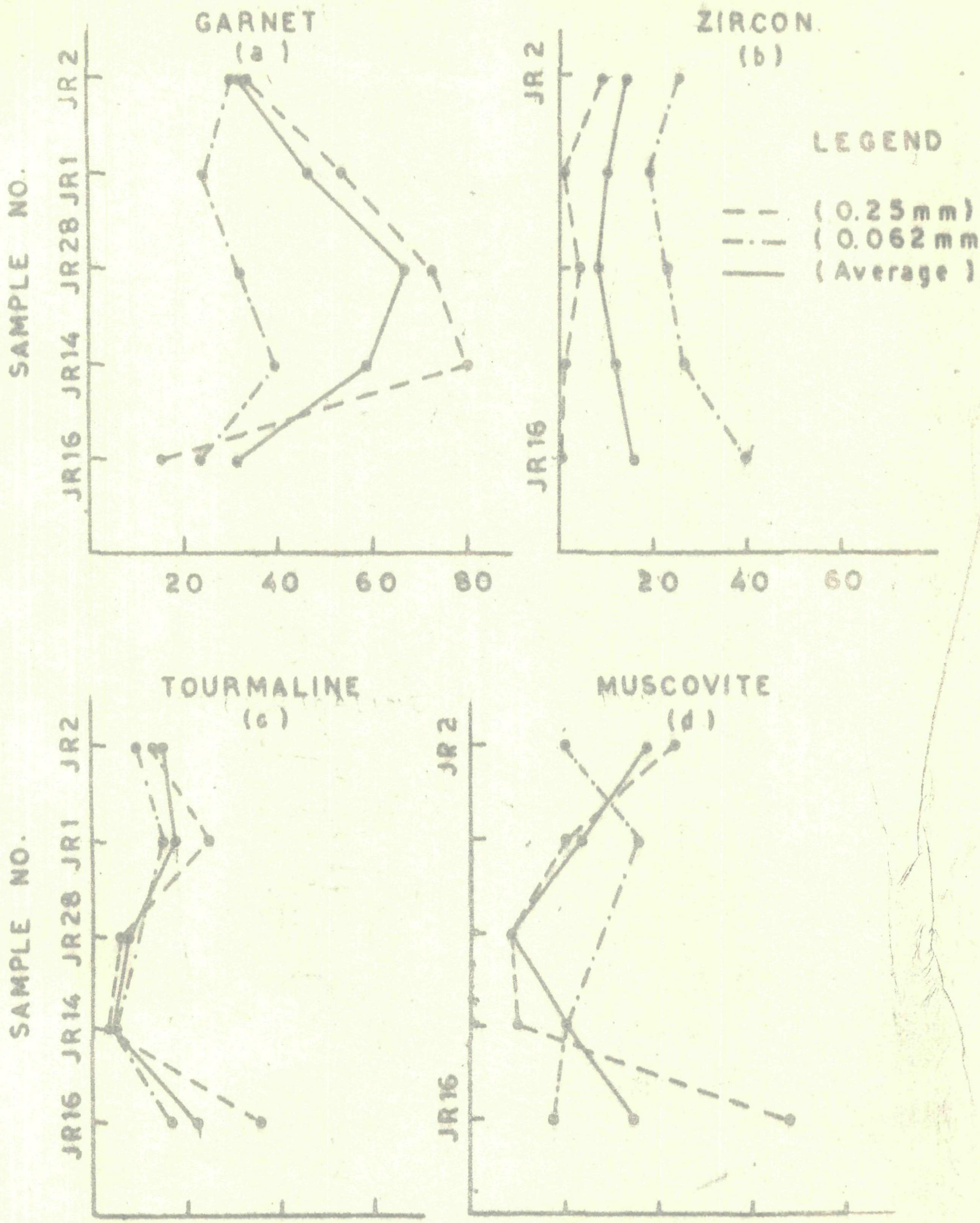

FIG. 16 : Graph showing relative percentage of heavy mineral species from lower (JR 16) to upper (JR 2) parts of Raniganj Formation and their variation from coarse (0.25 mm) to fine (0.062 mm) fractions and average percentage.

during the crushing of samples. The amount of broken grains is nevertheless more in finer fractions than the coarser ones (Table 14 ; Fig. 17 a).

It is either colourless, pink or brown. Brown garnet is less common than pink and colourless varieties. Garnet commonly occurs as irregularly fractured grains, though some grains may be subrounded to rounded (Plate 90). The surface of these grains is more often characterised by etching (Plate 90). Some grains show anamolous interference colours due to strain.

Tourmaline

Tourmaline occurs almost in same amount as recorded in the Barakar and Barren Measures, exception being the Talchir where it is scarce (Table 12).

Tourmaline suit of minerals is represented by brown, yellow, green and blue varieties. Brown, yellow and green tourmalines are more common, the last variety is rather rare. The various species of tourmaline show the same general characters as in the underlying formations. Most of the grains are subrounded to rounded (Plate 8c). Among inclusions, zircon, andalusite and magnetite are generally present.

Zircon

Zircon varies between 8.1 and 16.0 percent (Table 12). Amount of zircon increases systematically from coarse to fine

TABLE -13 : Average percentage of various heavy mineral species through different size fractions of sandstone facies of Raniganj Formation.

Size Fractions (mm) 6	0.25	0.149	0.074	0.062	Average
Mineralogy					
Garnet	50.89	57.37	42.83	29.45	45.13
Tourmaline	16.47	15.32	9.17	11.38	13.08
Zircon	3.17	4.06	17.68	31.96	14.26
Rutile	2.95	4.05	3.77	5.67	4.11

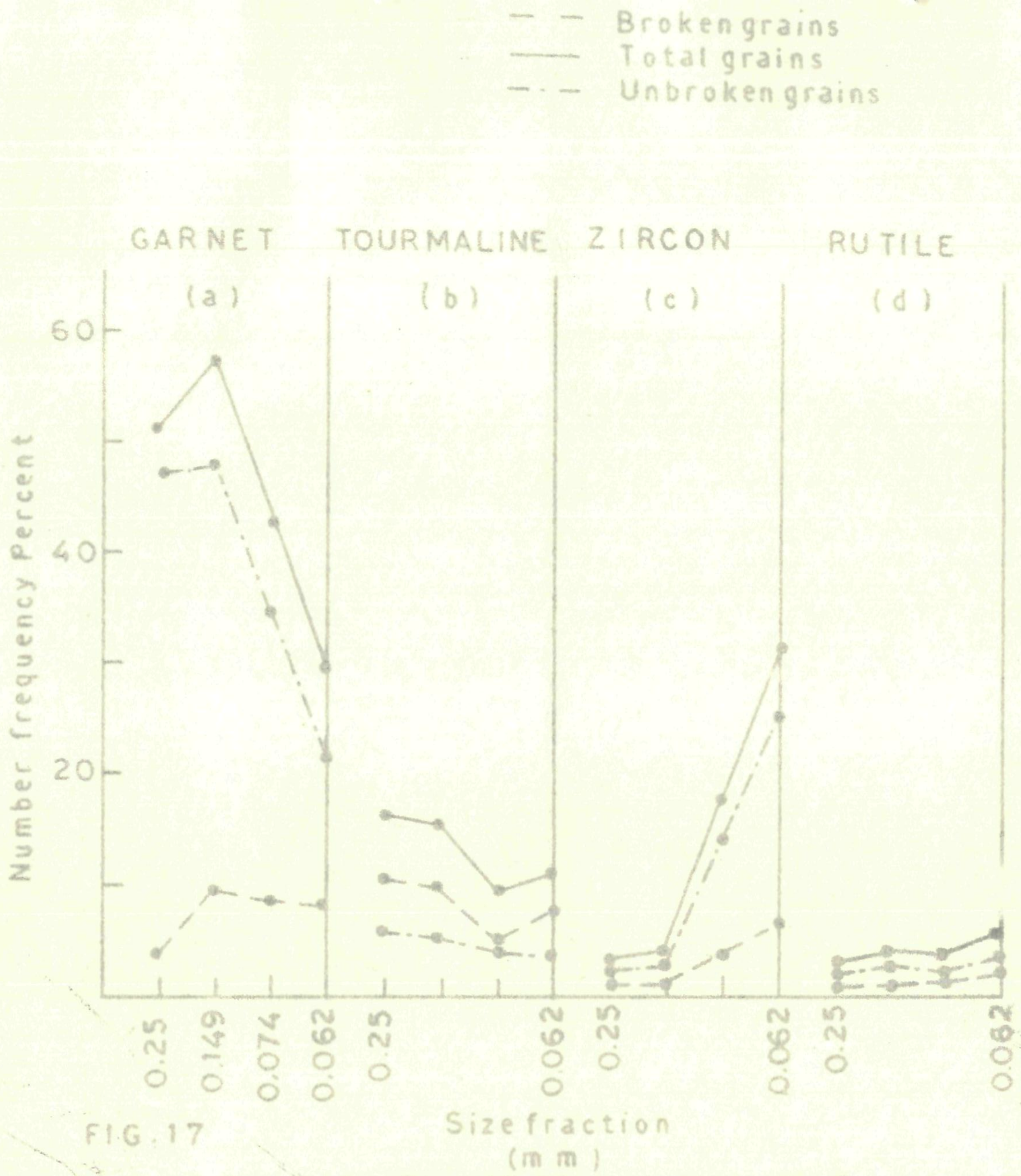

FIG. 17

Graph showing relative percentage of various broken and unbroken "heavy" grains through different size fractions and their total percentage in Raniganj Formation.

fraction in that, it varies from 3.1% (0.25 mm) through 4.0% (0.149 mm) and 17.8% (0.074 mm) to 31.9% (0.062 mm) (Table 13; Fig. 16 b). Relative percentage of broken grains also increases from coarse to fine fractions (Table 14; Fig. 17c).

Four varieties of zircon include, water clear, dusty, pink and green. They are commonly rounded to well rounded (Plate 9 k,l,m,n) though some subrounded grains may also occur (Plate 9 j,o,p). Inclusions of rutile, coloured zircon, apatite and biotite are common in the colourless zircon. Green and pink zircons are free from inclusions.

Sp Elongation ratio is almost same as observed in the Barren Measures ranging from 1 to 4.

Muscovite (including chlorite)

Micaceous minerals vary from 4.0 to 18.7% (Table 12) in which muscovite is more common than chlorite (2.0%). Like the Talchir, muscovite does not show any marked variation in different size fractions. These minerals show the same general characters as described earliar. Inclusions of zircon may be present in some grains of muscovite.

Epidote

Sp Epidote varies from 1.2 to 3.1% (Table 12). Most of these grains are green; some may be brownish pink. By and large, the percentage of epidote decreases from coarse to

TABLE - 14 : Average percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Raniganj Formation.

Size Fractions (mm)	0.15		0.149		0.074		0.062	
Mineralogy	B	U	B	U	B	U	B	U
Garnet	3.88	47.01	9.48	47.89	8.56	34.27	8.17	21.28
Tourmaline	10.55	5.92	9.71	5.61	5.04	4.13	7.80	3.58
Zircon	0.97	2.20	1.10	2.96	3.74	14.14	6.69	25.27
Rutile	0.87	2.08	1.12	2.93	1.45	2.32	2.08	3.59

B = Broken Grains

U = Unbroken Grains

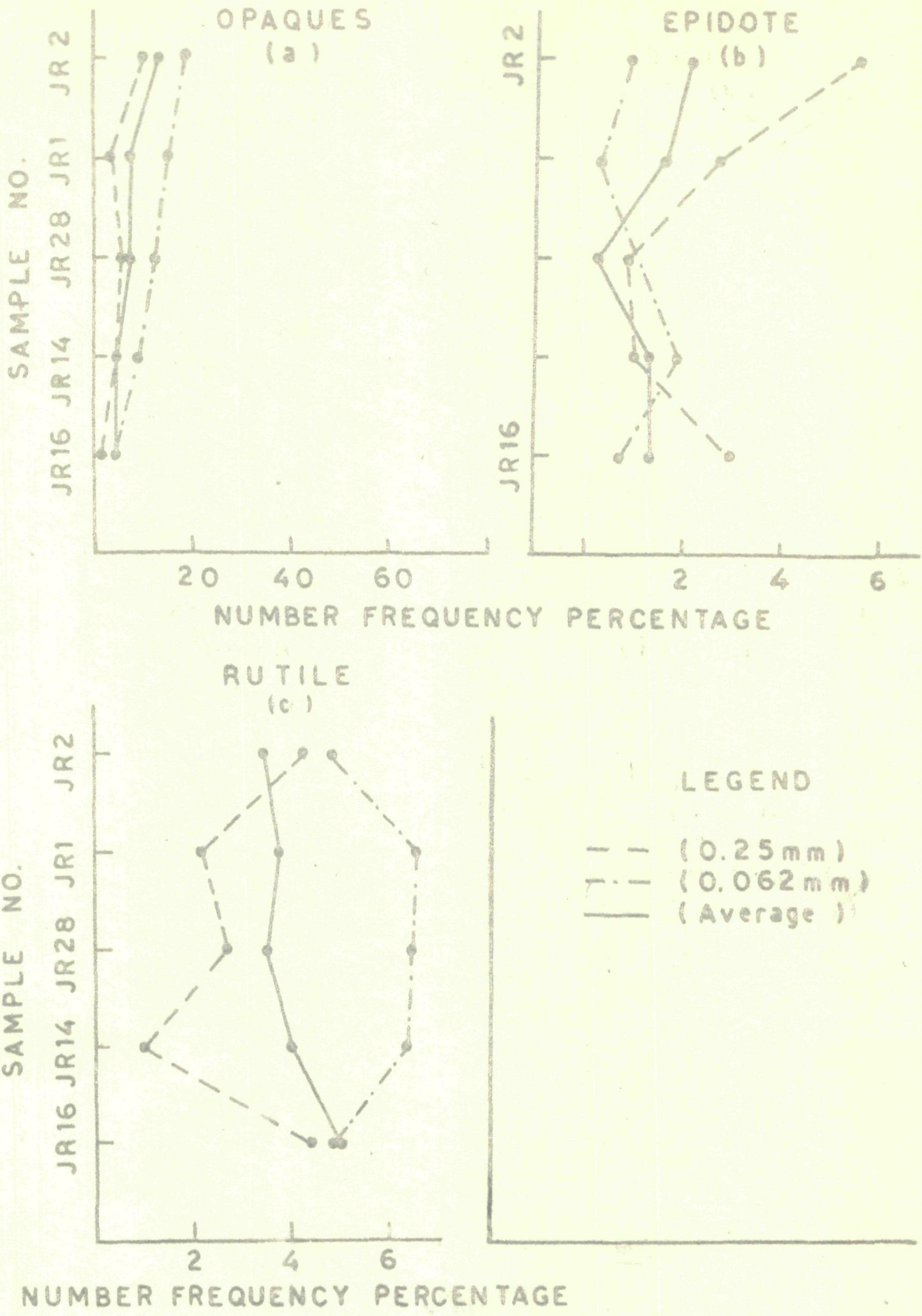

FIG. 18 : Graph showing relative percentage of heavy mineral species from lower (JR 16) to upper (JR 2) parts of Raniganj Formation and their variation from coarse (0.25 mm) to fine (0.062) fractions and average percentage.

fine fractions (Fig. 18b). Not uncommonly, the grains of epidote are very clear and free from inclusions. They are commonly rounded to well rounded, though some subangular grains may also present.

Rutile

Rutile varies from 3.4 to 4.9% It's content is not quite variable in different size fractions (Table 13; Fig. 18c). Fine fractions include more commonly, broken grains (Table 14; Fig. 17 d).

Rutile is present in two varieties: foxy red and reddish brown with amber tints. The second variety is more common in Raniganj Formation than in the Barakar. Rutile generally occurs in well formed prismatic crystals with pyramidal termination. Some clear crystals show diagonal striations (Plate 9r).

Other Minerals

Other heavy minerals identified in the Raniganj Formation are biotite (0.5 to 2.2%), anatase (0-.1%) and apatite (0-.1%), exhibiting general characters similar to those noted in the underlying formations.

Opaques

The amount of Opaques varies from 4.7 to 13.7% (Table 12) They show the same species and characters as described earliar. They are commonly rounded to well rounded; some grains are also subrounded to subangular.

The bar diagram in Fig. 19 shows the frequency distribution of heavy minerals in Raniganj Formation.

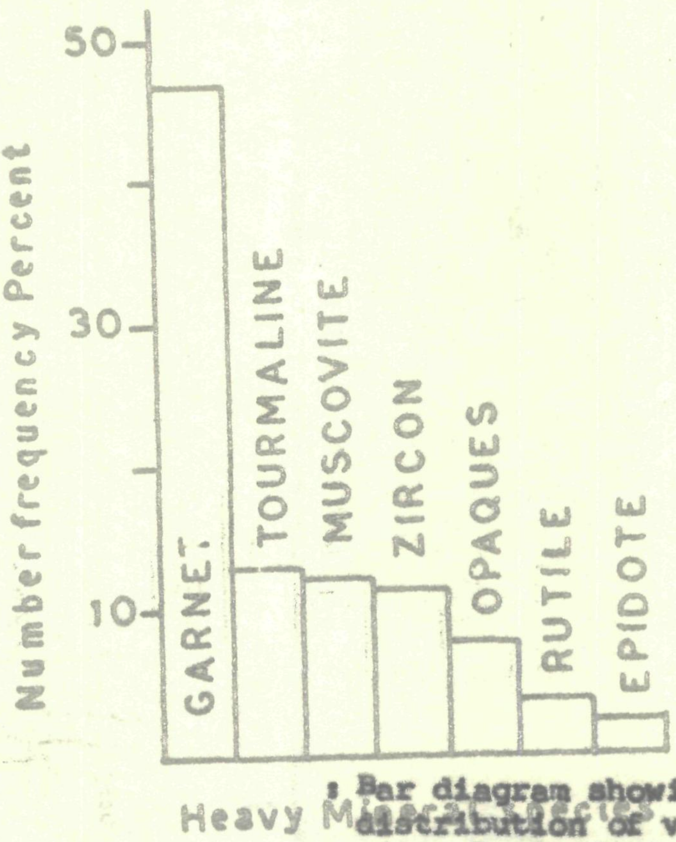

FIG.19 : Bar diagram showing frequency distribution of various heavy minerals in Raniganj Formation.

Chapter - IV

PROVENANCE

The composition of clastic rocks depends in part on the nature of the parent rock and in part on its maturity. Maturity is a function of time and intensity through which weathering is extended. Time and intensity are dependent upon relief and climate (Pettijohn, 1957). The task of the sedimentary petrographer is to determine the nature and composition of source rocks, and to deduce from the maturity of sediments, the nature of climate and relief. Therefore, an objective examination of major detrital constitutents can provide vitalclues for its place of origin and reconstruct the nature of source area.

Among the guides to provenance taken into consideration are:

1. Heavy mineral species
2. Types of detrital quartz
3. Detrital feldspar
4. Sandsized lithic fragments, and
5. Micas

Heavy minerals and provenance

Heavy minerals are of great value in studying provenance, transportation and weathering history of a sediment and in correlation. Shapes and roundness of the heavy minerals are sensitive indicators to the intensity of abraison. Sedimentary petrologists have defined certáin assemblages of heavy minerals which are indicative of a major class of source rocks (Krumbein and Pettijohn, 1938, p. 463; Baker, 1962, p. 90; Pettijohn, 1975, p. 487).

The heavy mineral assemblage in the sandstone and/or diamicitie (as the case may be) of the Jharia coalfield consists mainly of garnet, epidote, muscovite, tourmaline, zircon, tremolite-actinolite and rutile, with varying proportion in different formations.

The above suite of heavy minerals may have originated from a complex of acid to basic igneous rocks and low to high grade meta-sediments. Occasional occurrence of rounded zircon, garnet and epidote and subrounded tourmaline may suggest that part of these may have come from older sedimentary rocks, undergoing a second cycle of sedimentation. The small assemblage of opaque minerals (magnetite and ilmenite) may have been contributed from basic to ultrabasic igneous rocks.

The elongation ratio of zircon which ranges commonly from 1 to 4.5, suggests their derivation from quartzitic rocks. Occassionally elogation ratio may be as high as 6.5 suggesting the derivation of part of zircon from granitic rocks.

Evidence from Detrital quartz

Detrital quartz of sedimentary rocks is excellent indicator of the nature of the source rocks (Folk, 1961). About 75-85% of the detrital quartz is of monocrystalline type. Monocrystalline quartz showing smooth to slightly indulose extinction and roughly equidimensional in shape containing automorphic inclusions of tourmaline and zircon, may have been derived from granitoid source (Pettijohn, 1975 p. 201). The rest of monocrystalline quartz, elongated in shape, shows undulose extinction, is generally free from inclusions, may have come from older gneisses and schists (Folk, 1961).

The other major variety of quartz is polycrystalline. These quartz grains show straight to sutured inter-granular contacts. Some polycrystalline grains resemble stretched quartz (Folk, 1961). Polycrystalline quartz may have been derived from high grade metamorphic rocks (Blatt, 1967). Thus the characters of mono and polycrystalline quartz suggest their derivation largely from rocks varying from granite to granitic gneiss and schistose in composition.

<u>Evidence from quartzose fragments and chert</u>

According to Donaldson and Jackson (1965, p. 637), a possible source for quartzose fragments may be:

a, Phanerocrystalline pluotonic rocks

b, quartz vein, and

c, older sedimentary or meta-sedimentary rocks.

Fragments of chert may have been derived from older sedimentary rocks.

Evidence from Feldspar

Sandstones (or diamictite) in all the lower Gondwana formations of the Jharia coalfield are feldspathic and commonly contain potash feldspar including microcline, orthoclase and plagioclase. The feldspar may have come from granitoid and/or supracrustal (sedimentary and metamorphic) terrain.

A higher proportion of unaltered microcline may indicate that the source rocks containing feldspar did not undergo extensive weathering before the feldspathic debris was transproted and barried in the depositional basin without much reworking. Other species of feldspar are altered as well as fresh implying weathering in the source area and may indicate greater contribution from granitoid and supra-crustal rocks.

Evidence from Lithic fragments

The sandstones of the study area contain about 3 to 16.7% metasedimentary rock fragments, comprising phyllite, calcarious phyllite, magnetite phyllite, mica sp schist, hornblende schist, staurolite schist, quartzite schist, micaceous quartzite, feldspathic quartzite, siltstone, shale and basalt etc. These lithic fragments occur in variable proportion and suggest that low to high grade metasedimentary rocks constituted a good part of the provenance.

Evidence from Mica

Muscovite is more common than biotite. According to Folk (1961, p. 84) greatest source for the mica is the low grade metamorphic rocks.

Composition of Provenance

Petrographically these strata are mostly subarkose, lithic-subarkose to subarkosic wacke, lithic subarkosic wacke in composition, implying that the source rocks providing feldspathic debris for Talchir, Barakar, Barren Measures and Raniganj Formations were by and large, compositionally alike through time. The small differences in mineralogical composition including heavy minerals and grains size may be due to differences in the nature of weathering or be the results of differential abrasion and sorting during transportation, which in tern may be due to changes in paleohydraulics of depositing streams, climate and or tectonism.

The petrographic evidences cited above suggest a mixed provenance comprising:

i) acid igneous rocks (porphyritic granite and granite gneiss) intruded by pegmatite and quartz vein;

ii) low and high grade metasedimentary and sedimentary rocks particularly those of quartzose composition, argillite, phyllite and mica sehist and;

iii) a small proportion of basic to ultrabasic igneous rocks.

Location of Provenance

A paleocurrent study of the Jharia coalfield by Casshyap (1977, 1979) suggests that sediments were transported largely in the north-north westerly direction, indicating a provenance situated to the south of the area.

"Unclassified Precambrian" rocks outcrop extensively to the south of the study area. This region may possibly be the area where the provenance of the Gondwana sediments under investigation was located. This region is now largely covered by granite, gneisses and schists including outcrops of older epidiorite and closely correspond to that of chhotanagpur plateau.

Chapter - V

SUMMARY AND CONCLUSIONS

The Jharia basin is underlain by the four Late Paleozoic Gondwana formations, namely: Talchir, Barakar, Barren Measures and Raniganj, in ascending order. The present study was undertaken to evaluate pertrographic and heavy mineral composition of these formations. The study, based on random specimens shows petrographic similarities and differences between different formations from Talchir to Raniganj, as summarised below:

1. Talchir diamictite and sandstones are mostly lithic subarkosic wacke; some sandstones are lithic arkose to lithic subarkose. They are immature both texturally and mineralogically. Detrital grains are mostly angular to subangular. Monocrystalline quartz (20.1 - 42.4%) exceeds polycrystalline quartz (5 - 10.1%) and together forms the bulk of the detrital components. Percentage of quartz is more in sandstone than diamictite (Table 2). Feldspars are mostly unaltered. Percentage of feldspars is more in the sandstone (10.4 - 22.8%) than diamictite (8.2 - 13.1%). Lithic Fragments occur in the order of 6.2 - 23.8% and matrix 5 - 48.7%. Percentage of matrix in sandstone is however lower (5 - 28.2%) as compared to the diamictite (17.4 - 48.7%).

Garnet, epidote, muscovite, tourmaline, zircon and amphiboles (tremolite-actinolite) and titanite are among the heavy species that occur commonly.

2. Barakar sandstone is mostly subarkosic wacke; some are subarkose to lithic subarkosic wacke. They are submature to slightly immature. Detrital grains are mostly subangular to subrounded. Monocrystalline (40.8 - 50.5%) and polycrystalline quartz (5.2 - 10.5%) together forms the dominant detrital component. Feldspars are locally fresh but altered ones are more common. Amount of feldspars (7.2 - 15.9%) in Barakar sandstone is nearly same as in the Talchir diamictite (8.2 - 13.1%). Percentage of lithic rock fragments (3.1 - 8.5%) and matrix (11.1 - 23.6%) is comparatively lower in the Barakar sandstone.

Garnet, epidote and titanite show a marked decline whereas tourmaline, muscovite and opaques appear to increase in amount in the Barakar formation as compared to the Talchir.

3. All the specimens of Barren Measure sandstones (5) are subarkose; submature to slightly immature. Percentage of monocrystalline (38.1 - 55.2%) and polycrystalline quartz (6.4 - 12.8%) is nearly same as in the Barakar sandstones. Quartz grains are subrounded to subangular, so are most of the feldspars which increase slightly

(14.0 - 19.0%) in amount. Lithic rock fragments (2.4 - 5.8%) and matrix (5.7 - 12.5%) decrease further in contrast to the underlying Barakar and Talchir formations;

Heavy mineral species arealmost the same as in the underlying Talchir and Barakar formations, except that garnet which decreases in the Barakar is again well represented and titanite disappears completely in the Barren Measures (Table 9).

4. Raniganj sandstones are mostly subarkose to lithic subarkose; some are lithic arkose to arkose. They are submature texturally and mineralogically. Amount of monocrystalline quartz (33 -56%) and polycrystalline quartz (4.6 - 10.8%) is about the same as in the underlying Barren Measures (Table 2). Detrital grains of feldspars and quartz are mostly subrounded. Feldspars are both, fresh and altered and their amount is slightly more (9.0 - 27.5 %) in the Raniganj formation as compared to the underlying Barren Measure formation. Lithic fragments range from 2.8 - 10.6% and matrix from 1.3 - 9.7%. The lower amount of matrix is the result of cementation brought about by silica, carbonate and limonite. Fragments of petrified plants occur in some sandstones.

Percentage of garnet, zircon and rutile increases abruptly, whereas epidote and opaques decrease. The roundness of different heavy minerals consistantly improves from Talchir to Raniganj formations.

5. The effect of breaking on samples prepared for heavy mineral analysis, was examined on a suit of heavy minerals in different size fractions. The study reveals that detrital zircon followed by garnet show minimum breaking effect whereas tourmaline and rutile grains show maximum effect. Crushing effect is commonly more in the finer size fractions than in coarser ones.

6. This is suggested that roundness of detrital grains improves progressively, by and large from Talchir through Barakar and Barren Measures to Raniganj formation. A major part of the matrix in almost all the formations is secondary, derived as a result of crushing of the labile rock fragments.

7. Percentage of quartz consistantly increases from Talchir (25.2 - 52.5%), Barakar (46. - 61 %), Barren Measures (48.4 - 63%) to Raniganj formation (37.8 - 66.3). Detrital feldspar, likewise, shows a tendency to increase in amount from Talchir to Raniganj formation, with local exceptions. Lithic rock fragments do not show any systematic change but their overall percentage decrease

from Talchir to Raniganj. Percentage of matrix systamatically decreases from Talchir to Raniganj as shown in Table 2.

8. Petrographically the bulk of rocks underlying the Jharia basin are mostly felspathic lithic sandstones of wide varities as concluded above. The petrographic composition suggests a mixed provenance for Gondwana rocks of this area consisting of acid igneous rocks, low and high grade metasedimentary and sedimentary rocks and a small proportion of ultra basic igneous rocks.

9. The paleocurrent study of Jharia basin (Casshyap,1977, 1979) suggests that sediments were transported largely in the north-north westerly direction, indicating a provenance situated south of the study area.

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APPENDIX-I Modal analysis (in percent) of the lower and upper Talchir sandstone/diamictite of Jharia Basin

D = Diamictite

MINERAL COMPOSITION	SAMPLE NUMBER							
	JT_1	JT_2 (D)	JT_{2B} (D)	JT_4 (D)	JT_{12}	JT_{16}	JT_{19}	JT_{21}
<u>Quartz Resistates</u>								
Monocrystalline Quartz	42.40	25.80	31.40	20.15	30.15	42.15	27.28	31.95
Polycrystalline Quartz	10.10	5.00	9.10	5.10	9.95	7.45	7.23	6.95
Quartzose Fragments	4.10	12.50	2.00	5.00	6.50	3.20	8.81	7.32
<u>Feldspars</u>								
Microcline	15.25	10.10	8.50	5.10	14.38	17.52	6.22	6.66
Orthoclase	4.50	2.00	2.10	1.95	2.25	3.18	2.85	2.58
Plagioclase	3.00	1.00	1.00	1.15	1.20	2.10	1.35	1.17
Micas	0.30	0.00	0.60	0.00	1.00	0.00	1.03	1.50
Lithic Rock Fragments	12.15	23.80	6.2	10.50	13.75	11.30	16.70	12.68
Matrix	5.00	17.40	35.60	48.75	17.30	8.40	27.20	28.21
Accessories	3.00	2.30	3.40	2.30	3.50	4.30	1.01	0.78

APPENDIX-II Modal analysis (in percent) of the Barakar sendstones of Jharia Basin.

MINERAL COMPOSITION	SAMPLE NUMBER				
	JB_2 B	JB_5	JB_6	JB_9	JB_{11} B
<u>Quartz Resistates</u>					
Monocrystalline Quartz	44.21	45.75	49.80	40.80	50.50
Polycrystalline Quartz	10.25	8.95	9.50	5.20	10.50
Quartzose Fragments	6.84	8.99	8.70	4.50	8.00
<u>Feldspars</u>					
Microcline	5.54	6.50	4.60	9.25	12.50
Orthoclase	2.10	3.10	2.10	2.26	2.70
Plagioclase	1.45	0.00	0.50	1.50	0.70
Micas	0.80	0.50	0.96	0.25	0.20
Lithic Rock Fragments	8.50	6.65	6.28	7.21	3.10
Matrix	15.90	16.10	15.30	23.56	11.10
Cement	4.21	3.25	1.25	4.20	0.70
Accessories	0.20	0.20	0.80	1.25	0.00

APPENDIX-III Modal analysis (in percent) of Barren Measures sandstones of Jharia Basin.

MINERAL COMPOSITION	SAMPLE NUMBER				
	6/2	6/6	7/9	7/12	8/2
Quartz Resistates					
Monocrystalline Quartz	55.28	48.18	50.12	38.12	50.12
Polycrystalline Quartz	6.42	8.44	12.10	10.34	12.86
Quartzose Fragments	3.79	2.15	2.10	2.50	3.58
Feldspars					
Microcline	11.48	8.42	8.22	11.11	12.13
Orthoclase	4.40	2.14	3.95	2.20	1.25
Plagioclase	3.10	3.48	4.40	3.50	3.15
Micas	2.16	3.14	2.18	0.20	1.50
Lithic Rock Fragments	3.10	4.15	3.57	2.45	5.86
Matrix	7.60	12.56	7.96	7.02	5.78
Cement	1.88	5.81	4.12	21.5	3.30
Accessories	0.51	1.00	1.20	1.00	0.00

APPENDIX-IV Modal analysis (in percent) of Raniganj sandstones of Jharia Basin.

MINERAL COMPOSITION	SAMPLE NUMBER									
	JR_{16}	JR_{2}	JR_{1}	JR_{13}	JR_{14}	JR_{10}	JR_{20B}	JR_{22}	JR_{20}	JR_{28}
Quartz Resistates										
Monocrystalline Quartz	44.52	56.10	55.55	40.15	38.70	39.95	39.91	43.40	83.74	33.00
Polycrystalline Quartz	10.48	7.80	10.85	9.25	6.10	8.95	6.89	8.50	9.86	4.80
Quartzose Fragments	7.10	4.40	3.10	5.80	1.70	1.40	0.90	1.00	2.00	1.00
Feldspars										
Microcline	3.60	5.10	5.70	12.30	19.60	20.00	12.20	6.20	8.50	5.40
Orthoclase	2.50	5.40	4.90	5.00	3.10	2.90	8.00	7.50	4.00	1.50
Plagioclase	3.80	2.90	2.00	3.10	2.00	4.40	6.10	3.50	4.60	2.10
Micas	3.70	2.20	2.20	1.00	0.50	0.80	1.10	1.00	1.00	0.20
Lithic Rock Fragments	9.50	6.80	6.50	4.80	10.80	6.10	10.10	10.50	2.80	0.00
Petrified Plant Fragments	-	-	-	-	-	-	-	-	-	15.40
Cement	4.70	3.20	2.90	5.50	12.10	14.20	7.30	10.80	9.40	33.60
Matrix	9.70	5.60	5.40	11.00	5.30	1.30	7.50	7.80	3.70	3.00

APPENDIX -V Recalculated percentage of Detrital Constituents of Talchir sandstone/Diamictite of Jharia Basin.

D= Diamictite

DETRITAL CONSTITUENTS	SAMPLE NUMBER							
	JT_1	JT_2(D)	JT_{2B}(D)	JT_4 (D)	JT_{12}	JT_{16}	JT_{19}	JT_{21}
Quartz Resistates	61.65	53.99	69.78	61.79	58.85	60.75	60.61	65.27
Feldspars	24.78	60.33	19.04	16.75	22.51	26.23	14.57	14.70
Lithic Rock Fragments	13.56	29.67	11.16	21.45	18.62	13.00	24.80	20.02
TOTAL:	99.99	99.99	99.98	95.99	99.96	99.98	99.98	99.99

APPENDIX -VI Recalculated percentage of Detrital constituents of Barakar sandstones of Jharia Basin.

DETRITAL CONSTITUENTS	SAMPLE NUMBER				
	JB_{2E}	JB_5	JB_6	JB_9	JB_{11B}
Quartz Resistates	76.92	79.17	82.48	71.15	78.23
Feldspars	11.40	11.93	8.73	18.33	18.02
Lithic Rock Fragments	11.67	8.88	8.78	10.51	3.74
TOTAL :	99.99	99.98	99.99	99.99	99.99

APPENDIX-VII Recalculated percentage of Detrital constituents of Barren Measures sandstones of Jharia Basin.

DETRITAL CONSTITUENTS	SAMPLE NUMBER				
	6/2	6/6	7/9	7/12	8/2
Quartz Resistates	72.99	73.37	74.24	72.37	73.59
Feldspars	21.15	17.52	19.13	23.87	18.28
Lithic Rock Fragments	5.86	9.10	6.64	3.76	8.14
TOTAL :	100.00	100.00	100.00	100.00	100.00

APPENDIX- VIII Recalculated percentage of Detrital con-stituents of Raniganj sandstones of Jharia Basin.

DETRITAL CONSTITUENTS	SAMPLE NUMBER									
	JR_{16}	JR_{2}	JR_{1}	JR_{13}	JR_{14}	JR_{10}	JR_{20B}	JR_{22}	JR_{20}	JR_{2B}
Quartz Resistates	72.88	75.38	76.69	68.15	56.36	69.41	56.03	64.82	75.70	81.00
Feldspars	11.61	14.79	13.79	24.79	29.93	32.45	30.85	21.07	19.60	18.60
Lithic Rock Fragments	15.49	9.82	9.50	7.04	13.69	8.12	13.10	14.09	4.40	0.40
TOTAL:	99.98	99.99	99.98	99.98	99.98	99.98	99.98	99.98	99.70	100.00

Frequency percentage of various heavy minerals species through different size fractions of diamictite /sandstone facies of Talchir Formation in Jharia basin.

	JT_2				JT_4				JT_{12}				JT_{19}			
0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062
50.25	73.83	65.38	63.21	49.05	59.47	56.75	36.94	38.80	63.51	71.2	61.5	54.16	19.51	8.13	12.63	9.16
15.06	8.85	20.18	10.74	12.72	21.53	20.08	23.38	18.0	14.7	13.66	20.62	15.96	5.87	28.45	9.75	18.38
10.05	-	-	7.42	11.22	-	-	5.41	6.4	-	-	0.78	1.38	3.12	0.81	19.51	20.16
-	-	-	0.82	-	1.02	0.87	1.33	1.2	0.58	-	-	-	35.51	24.39	29.26	9.62
-	-	-	0.41	0.74	0.50	-	-	-	0.58	1.0	0.79	1.38	1.56	2.43	4.92	1.83
6.53	3.84	4.32	2.06	1.87	1.53	4.36	2.03	3.6	5.29	2.87	2.38	2.08	-	1.0	0.48	-
10.05	6.15	4.32	4.13	10.11	6.16	6.11	16.96	12.0	6.47	6.91	6.34	8.33	21.69	23.38	8.29	21.06
-	-	-	4.94	5.61	1.53	6.54	8.12	6.8	7.04	2.15	1.98	9.27	6.09	6.50	5.85	9.62
-	1.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.51	-	0.96	1.23	2.44	-	-	1.01	1.2	-	-	-	0.69	-	1.62	2.43	3.21
5.25	6.15	4.80	4.95	6.36	8.20	5.24	4.74	12.00	1.76	2.15	5.55	6.25	7.60	3.25	6.82	6.88

ncy percentage of various heavy mineral species through different size fractions
ndstone facies of Barakar Formation in Jharia basin.

.		JB-5		.		JB-6		.		JB-9		.		JB-11B		
0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.06
1.25	8.43	1.42	0.89	0.56	-	-	1.5	0.95	11.45	8.38	22.32	-	20.76	38.23	8.78	10.92
5.0	3.61	3.57	8.96	9.55	-	3.88	5.5	13.09	2.67	1.79	9.78	8.30	3.27	0.98	6.06	10.30
22.08	10.84	35.71	18.83	14.04	20.49	23.30	12.50	21.40	13.35	17.36	19.87	16.61	31.14	27.45	13.63	23.02
23.33	38.55	31.42	32.73	33.70	8.19	25.24	36.5	15.01	9.16	19.16	4.58	37.07	8.19	18.62	37.87	18.90
-	1.20	-	0.44	-	-	-	-	0.31	-	0.59	-	-	-	0.98	0.30	0.34
4.16	13.25	7.14	10.31	8.42	30.32	26.21	22.5	15.97	4.58	5.98	4.89	8.62	3.27	2.45	4.54	4.81
0.41	-	2.14	0.89	1.12	0.81	2.91	2.0	1.27	0.76	0.59	1.52	0.95	1.09	2.45	0.90	1.03
36.25	16.86	11.42	17.93	28.08	40.16	18.44	18.0	27.15	54.19	35.92	33.63	23.0	28.41	7.84	26.66	28.52
-	-	-	0.89	-	-	-	-	-	3.05	-	0.91	0.63	-	-	-	0.34
3.75	2.24	4.28	1.79	1.40	-	-	0.50	0.95	0.76	6.58	1.83	0.95	3.27	-	0.60	1.37
3.34	4.81	1.42	3.58	1.40	-	-	1.0	2.87	-	3.59	0.61	2.87	0.54	0.98	0.60	0.34
0.41	-	1.42	2.69	1.68	-	-	-	0.95	-	-	-	0.95	-	-	-	-

Frequency percentage of various heavy mineral species through different size fractions of sandstone facies of Barren Measures in Jharia basin.

	.	7/12			.	7/9			.	6/6			.	6/2			
0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.06
0.52	12.50	0.89	-	8.01	11.91	3.27	1.31	15.70	11.83	-	3.17	11.33	13.93	-	0.77	6.06	19.7
8.94	19.31	12.50	23.64	16.61	14.95	16.39	16.06	15.94	15.21	-	6.34	28.57	24.04	3.57	17.05	24.24	21.9
1.05	1.70	0.89	-	1.78	0.93	-	0.98	0.76	3.09	-	1.58	0.9	1.74	-	0.38	0.69	0.2
8.94	9.09	30.35	43.34	43.02	38.58	9.83	66.22	39.84	46.47	-	7.14	6.80	8.71	-	1.16	9.79	13.0
11.57	10.22	8.92	3.94	9.49	9.81	21.31	3.27	6.13	9.85	-	23.80	12.47	12.19	7.14	8.13	12.82	11.
11.05	13.06	13.39	8.41	8.90	9.34	22.95	3.27	4.59	4.78	-	20.63	12.24	8.71	46.42	26.74	9.09	7.
1.57	1.70	5.35	7.38	2.07	0.70	11.47	1.96	0.76	0.56	-	-	1.36	2.09	7.14	5.81	1.86	0.
25.26	32.38	27.67	16.25	10.08	13.78	14.75	6.55	16.85	7.88	-	33.33	26.30	28.57	21.42	37.98	34.73	24.
-	-	-	-	-	-	-	-	-	-	-	3.17	-	-	7.14	1.54	0.46	0.
0.52	-	-	-	-	-	-	0.32	0.38	0.28	-	0.79	-	-	7.14	0.38	0.23	
0.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

equency percentage of various heavy mineral species through different
ze fractions of sandstone facies of Raniganj Formation in Jharia basin.

			JR 14				SR 28				JR 1				JR 2		
	.				.				.				.				
74	0.062	0.25	0.149	0.074	0.062	0.25	0.849	0.074	0.062	0.25	0.149	0.074	0.062	0.25	0.149	0.074	0.062
18	23.45	80.25	72.84	43.92	39.50	72.65	68.93	59.99	-	53.94	63.10	844.49	24.27	32.64	34.43	27.64	30.61
58	39.82	1.07	1.14	20.67	25.85	4.67	7.37	12.24	-	0.55	3.95	16.74	18.58	8.69	3.98	20.17	24.63
46	16.81	2.83	3.42	8.20	4.24	6.16	10.16	5.57	-	24.67	15.42	10.52	15.48	13.0	26.59	9.13	9.0
12	4.86	1.07	3.42	5.16	6.38	2.73	3.27	4.57	-	2.23	3.42	2.87	6.63	4.34	2.65	2.17	4.83
61	8.84	5.37	6.57	18.08	9.85	4.34	3.27	4.58	-	10.17	7.36	11.48	17.69	21.73	13.29	30.43	9.66
-	-	2.15	2.85	2.58	1.46	0.93	-	1.15	-	0.55	0.52	1.91	-	2.17	0.53	-	-
-	1.76	2.07	1.17	3.06	2.92	1.86	1.22	0.75	-	3.67	3.0	2.39	1.32	6.52	2.53	1.73	1.93
2.06	4.42	4.67	7.42	1.29	9.75	6.60	5.73	10.78	-	4.17	2.63	9.56	15.48	10.86	15.95	8.69	19.32
-	-	-	0.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	0.50	-	0.03	-	-	-	+	-	0.50	-	-	-	-	-	-

APPENDIX - XIII

Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of diamictite/sandstone facies of Talchir Formation in Jharia basin.

Sample No.	JT 1								JT 2										
Size Fractions(mm)	0.25		0.149		0.074		0.062		0.25		0.149		0.074		0.062		0.25		[illegible]
Mineralogy		U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
Garnet	9.03	67.78	13.30	39.42	14.18	37.84	15.07	35.18	7.69	66.14	9.61	55.77	11.57	51.64	12.73	36.32	5.64	53.83	12.66
Epidote	-	8.46	10.21	9.01	11.51	11.10	7.06	8.00	1.15	7.30	8.08	12.10	5.24	5.40	6.50	6.22	4.11	17.42	8.23
Zircon	-	0.56	-	-	1.0	5.08	2.05	8.00	-	-	-	-	1.02	6.40	1.37	9.35	-	-	-
Tourmaline	-	-	1.00	-	1.01	-	-	-	-	-	-	-	0.82	-	-	-	1.02	-	0.87
Rutile	-	-	-	0.96	-	-	-	-	-	-	-	-	-	0.41	-	0.74	-	0.5	-

Sample No.		JT 4							JT 12								JT 19				
Size Fractions(mm)	.149	0.149	0.074	0.062		0.25		0.149		0.074		0.062		0.25		0.149		0.074			0.062
Mineralogy	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
Garnet	44.09	9.15	27.79	9.20	29.6	8.82	54.69	14.82	55.38	13.09	48.41	13.88	40.28	13.41	6.1	3.93	4.2	6.23	6.35	5.50	3.66
Epidote	11.88	11.36	12.02	10.34	7.66	4.1	10.6	6.81	6.85	12.86	7.76	10.76	5.20	-	4.87	16.10	12.35	6.0	3.75	12.82	5.56
Zircon	-	1.01	4.4	2.0	4.4	-	-	-	-	-	0.78	-	1.38	3.12	-	0.81	-	5.09	14.42	5.16	15.00
Tourmaline	-	1.0	0.33	1.2	-	0.58	-	-	-	-	-	-	-	30.82	4.69	21.25	3.14	21.93	7.33	5.5	4.12
Rutile	-	-	-	-	-	-	0.58	0.5	0.5	0.39	0.39	0.69	0.69	-	1.56	0.81	1.62	2.46	2.46	0.45	1.38

B = Broken Grains

U = Un-broken Grains

APPENDIX - XIV

Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Barakar Formation in Jharia basin.

Sample No.	JB 2 B								JB 5								JB 6				
Size Fraction(mm)	0.25		0.149		0.074		0.062		0.25		0.149		0.074		0.062		0.25		0.149		0.074
Mineralogy	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
Garnet	-	1.83	-	-	1.01	1.01	1.25	-	4.81	3.62	0.71	0.71	-	0.89	0.56	-	-	-	-	-	1.5
Zircon	-	2.75	-	-	3.24	6.89	1.00	4.0	3.61	-	0.71	2.86	3.13	5.83	3.65	5.9	-	-	2.0	1.88	2.0
Tourmaline	3.66	-	32.46	3.68	32.66	3.48	17.96	4.10	9.64	1.2	33.57	2.14	17.48	1.35	12.92	1.12	17.62	2.87	19.92	3.38	10.36
Epidote	7.33	8.26	6.78	7.89	3.21	3.21	3.0	1.16	11.10	2.10	6.0	1.14	8.95	1.35	8.42	-	15.65	14.67	16.45	9.76	12.68
Rutile	5.23	2.1	4.31	1.07	-	2.02	-	0.41	-	-	2.14	-	0.89	-	0.56	0.56	0.81	-	0.81	2.1	-

Sample No.	JB 6			JB 9								JB 11B							
Size Fraction(mm)	0.074	0.062		0.25		0.149		0.074		0.062		0.25		0.149		0.074		0.062	
Mineralogy	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
Garnet	-	0.95	-	6.87	4.58	3.59	4.79	15.29	7.03	-	-	28.93	9.83	13.72	24.51	5.15	3.63	7.56	3.43
Zircon	5.5	4.4	8.69	0.76	1.92	-	1.79	2.75	7.03	4.15	4.15	1.09	2.18	-	0.98	2.43	3.63	4.81	5.49
Tourmaline	2.14	19.25	2.15	11.44	1.91	14.37	2.91	16.2	3.67	14.37	2.24	16.05	1.09	26.47	0.98	12.43	1.20	21.3	1.72
Epidote	9.82	10.09	5.88	1.91	2.67	2.99	2.99	2.44	2.44	5.74	3.88	3.27	-	1.96	0.49	3.64	0.90	4.0	0.81
Rutile	2.0	-	1.27	0.38	0.38	0.59	-	0.61	0.91	0.32	0.83	1.09	-	1.47	0.88	0.90	-	0.68	0.35

B = Broken Grains

U = Unbroken Grains

APPENDIX -XV

Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Barren Measures in Jhaira basin.

Sample No.	8/2								7/12								7/9				
Size Fractions(mm)	0.25		0.149		0.074		0.062		0.25		0.149		0.074		0.062		0.25		0.249		
Mineralogy	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
Zircon	0.82	4.5	-	0.67	2.1	8.43	2.87	9.65	0.89	-	-	-	3.56	4.45	5.37	6.54	-	3.27	-	1.31	5.74
Tourmaline	6.97	1.63	15.43	6.71	5.79	3.15	13.06	6.25	11.61	0.89	18.23	5.41	13.05	3.56	11.92	3.03	14.76	1.63	9.84	6.22	9.96
Rutile	-	-	-	1.67	0.53	0.52	0.57	1.13	-	0.89	-	-	1-42	0.29	0.47	0.46	-	-	0.33	0.65	-
Garnet	10.65	23.36	8.39	16.10	12.63	16.31	5.69	3.40	6.25	24.10	17.24	26.10	24.71	18.27	25.24	13.31	6.56	3.27	9.5	56.72	23.75
Epidote	3.60	4.5	0.34	2.35	5.79	5.78	3.41	6.81	3.92	-	3.94	-	6.53	2.96	6.31	3.50	21.31	-	2.29	0.98	2.69

Sample No.				6/6									6/2						
Size Fractions(mm)	0.074	0.062		0.25		0.149		0.074		0.062			0.25		0.149		0.074		0.062
Mineralogy	B	B	U	B	U	B	U	B	U	B	U		B	U	B	U	B	U	B
Zircon	9.96	5.92	5.91	-	-	0.79	2.38	2.49	8.84	1.39	12.54	-	-	-	0.77	1.4	4.66	6.78	13.0
Tourmaline	4.98	12.4	2.31	-	-	3.17	3.17	16.1	12.47	12.2	11.84	-	3.57	16.28	0.77	20.05	4.19	19.79	2.16
Rutile	0.76	1.97	1.12	-	-	1.58	-	0.2	0.68	0.70	1.04	-	-	-	0.38	0.23	0.46	0.27	-
Garnet	16.09	30.14	16.33	-	-	3.18	3.96	4.68	2.72	4.88	3.83	-	-	0.39	0.77	3.27	6.52	7.59	5.41
Epidote	3.44	6.19	3.66	-	-	15.07	8.73	7.71	4.76	7.67	4.52	-	7.14	7.36	0.77	9.79	3.03	10.57	1.35

B = Broken Grains

U = Unbroken Grains

APPENDIX - XVI   Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Raniganj Formation in Jharia basin.

ple No.	JR 16								JR 14								&	
e Fractions (mm)	0.25		0.149		0.074		0.062		0.25		0.149		0.074		0.062		0.25	
eralogy	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
net	2.54	12.49	10.51	37.08	8.19	29.95	7.15	16.3	5.15	75.1	6.13	66.71	8.29	35.63	8.95	30.55	4.21	68.44
rcon	-	0.88	0.91	3.03	3.15	16.43	10.25	29.57	0.25	0.82	0.31	0.83	5.16	15.51	9.0	16.85	1.02	3.65
rmaline	24.91	10.83	17.10	3.98	10.40	8.06	12.20	4.61	1.05	1.78	1.70	1.72	3.10	2.10	3.10	1.14	4.15	2.01
ile	1.45	2.97	2.15	4.38	1.50	2.62	2.10	2.76	-	1.07	1.10	3.32	2.10	3.06	1.05	5.34	0.75	1.98

	JR 28						JR 1								JR 2						
	0.149		0.074		0.062		0.25		0.149		0.074		0.062		0.25		0.149		0.074		0.062
	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
	8.15	60.78	8.65	51.34	-	4.93	49.01	15.77	47.33	12.50	31.99	8.39	16.88	2.59	30.05	6.85	37.58	5.18	22.46	8.19	22.42
	2.1	5.27	2.65	9.59	-	-	0.55	1.20	2.74	2.59	14.15	2.60	15.98	3.59	5.1	1.02	2.96	5.15	15.02	4.92	19.71
	6.98	3.18	3.57	2.0	-	18.51	6.16	2.85	12.57	2.15	9.37	8.69	6.79	4.16	8.84	19.95	6.64	6.01	3.12	7.21	1.79
	1.0	2.27	1.06	3.51	-	-	2.23	0.79	2.63	1.20	1.67	2.10	4.53	2.17	2.17	0.6	2.05	1.40	0.77	3.1	1.73
	0.75	1.98	1.0	2.27	1.06	3.51	-	-	2.23	0.79	2.63	1.20	1.67	2.10	4.53	2.17	2.17	0.60	2.05	1.40	0.77

B = Broken Grains

U = Unbroken Grains

JB13	JB 16	8/2
0.07	0.08	0.13
0.8	0.09	0.39
0.4	0.04	0.16
0.2	0.12	1.2
0.39	0.08	0.4

BARREN MEASURES				RANIGUNJ						
7/12	7/9	6/6	6/2	JR 1	JR 2	JR 14	JR 16	JR20	JR20B	JR28
0.4	0.06	2.9	0.05	0.15	0.03	0.6	0.2	0.3	0.1	0.2
0.4	1.1	0.08	0.08	0.4	0.15	0.8	1.08	0.04	0.08	0.8
0.08	0.06	0.08	0.08	0.02	0.10	0.2	0.2	0.02	0.03	0.26
0.6	0.04	0.05	0.08	0.5	0.1	0.08	0.1	0.02	0.03	0.03
0.38	0.3	0.77	0.07	0.27	0.1	0.4	0.4	0.05	0.06	0.33
			0.39							0.24

LIST OF APPENDIX

APPENDIX-XII Frequency percentage of various heavy mineral species through different size fractions of sandstone facies of Raniganj Formation in Jharia basin.

APPENDIX-XIII Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of diamictite/ sandstone facies of Talchir Formation in Jharia basin.

APPENDIX-XIV Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Barakar Formation in Jharia basin.

APPENDIX-XV Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Barren Measures in Jharia basin.

APPENDIX-XVI Frequency percentage of various broken and unbroken heavy mineral species through different size fractions of sandstone facies of Raniganj Formation in Jharia basin.

APPENDIX-VII Average percentage(by weight) of heavy minerals through different size fractions of various formations of Jharia basin.